82d Congress
1st Session

COMMITTEE PRINT

FUEL RESERVES OF THE UNITED STATES

A STATEMENT

PREPARED BY THE

UNITED STATES GEOLOGICAL SURVEY

AT THE REQUEST OF THE

COMMITTEE ON INTERIOR AND INSULAR AFFAIRS UNITED STATES SENATE

ON

FUEL RESERVES OF THE UNITED STATES

Printed for the use of the
Committee on Interior and Insular Affairs

UNITED STATES
GOVERNMENT PRINTING OFFICE
80424 WASHINGTON : 1951

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UNITED STATES DEPARTMENT OF THE INTERIOR,
OFFICE OF THE SECRETARY,
Washington 25, D. C., March 2, 1951.

Hon. JOSEPH C. O'MAHONEY,
Chairman, Committee on Interior and Insular Affairs,
United States Senate, Washington 25, D. C.

MY DEAR SENATOR O'MAHONEY: Attached is a statement, Fuel Reserves of the United States, prepared by the Geological Survey for the use of your committee. We feel that this material will be of assistance to your committee in connection with the study you are conducting.

Much of this material was incorporated within the document Basic Data Relating to Energy Resources, printed for Senate committee use early this year. Illustrations that accompany the report are transmitted flat in order to preserve their condition for reproduction.

Please let me know if I can be of further assistance in this matter.

Sincerely yours,

OSCAR L. CHAPMAN,
Secretary of the Interior.

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FUEL RESERVES OF THE UNITED STATES

A Statement by the United States Geological Survey[1]

Introduction

Data on the fuel reserves of the United States are voluminous and detailed. These data result from many years of work by the United States Geological Survey and other Federal agencies, by the geological surveys and conservation and development organizations of the several States, by research institutions, and by private industry acting on individual initiative and in concert through group and association effort. Despite the vast volume of data that has been thus assembled, the fuels reserves of the United States are still inadequately known. This is due principally to the scope, complexity, and size of the problem, and in part to some fundamentally indeterminate factors in analysis.

Much is known, however, or can be deduced from existing knowledge, on the status of our fuel reserves, and the adequacy of our knowledge is constantly improving, particularly so in recent years with the growing general realization that an adequate inventory of our national resources is an imperative need. This statement attempts to summarize the present state of knowledge and opinion as to resources of the mineral fuels and to review the adequacy, significance, and interrelationships of these reserves, primarily from a geologic point of view. It is not definitive or final. Appraisals of reserves cannot be such because of the nature of geologic occurrence in the earth of the several carbonaceous and hydrocarbon substances used as fuel. It is therefore necessary to scrutinize what actually is meant by the quantitative statements that are made of our fuel reserves.

The Meaning of Reserves

Webster gives as the primary definition of the noun "reserve": "That which is reserved; something kept back or withheld, as for future use; a store; stock; an extra supply." In the discussion of reserves of mineral fuels, this fundamental definition soon proves inadequate to describe meaningfully what is meant by "reserves."

The complexity of the concept of reserves has led to diverse classifications of reserves with a multiplicity of terms to describe our mineral and fuel resources: original reserves; measured, indicated, and inferred reserves; proved, probable, and possible reserves; potential reserves; minable and recoverable reserves. These are among the terms most frequently employed. All of them mean different things, and the computation of each results in a different quantity.

The computed size of reserves depends on many factors, some of which are independent of each other and others are interrelated in

[1] Data for this statement were supplied by the following members of the staff of the U. S. Geological Survey: Paul Averitt, A. A. Baker, L. R. Berryhill, G. V. Cohee, C. H. Dane, D. C. Duncan, and J. D. Love.

varying ways; among the most important of these are: The distribution of the material in the earth's crust, accessibility, techniques of recovery, processing and utilization, and the economics of price, transportation, and substitution.

These factors determine the approach we must take to the concept of reserves. Reserves are never static and unchangeable. They are dynamically linked with the technological progress of mankind, and continually are subject to the impact of scientific development in discovery, recoverability, and utilization of our mineral fuels resources. Any discussion of the subject of reserves must be founded on a clear understanding of the meaning of the various categories of reserves.

Estimates of the total quantity of the various elements or minerals present in the earth have been made, but are not pertinent to our understanding of reserves. Though exceedingly large in the aggregate, the substances may be disseminated so minutely through the rocks or so deeply buried that they cannot be considered "as for future use; a store; stock; an extra supply." Only those quantities of a substance for which some evidence is available to indicate concentrations of potential economic value, at depths in the earth's crust believed to be accessible for exploitation, may be regarded as reserves. These quantities—total reserves known to be present in the ground at the present time—are our basic reserves. These basic reserves can be computed, estimated, or inferred with varying degrees of accuracy, depending on the nature of the occurrence and the character and extent of the available geologic data. Certain fundamental assumptions are, of course, required before basic reserves can be computed. Such assumptions must be made for the size and thickness of the deposits to be included, their grade, and their depth.

The quantities of basic reserves thus calculated are independent of the percentage of recovery attainable by current methods and the costs of extraction that may or may not permit their recovery at a profit. They do, however, furnish the basic data to which economic and technologic considerations can be applied.

After the fundamental assumptions have been made and specifically stated, several classes of reserves may be distinguished according to the adequacy of the data concerning them.

Estimates of basic reserves are subject to change in several ways:

1. By new discoveries that add to knowledge of the quantity of the material. For some substances, the rate of discovery causes continuous change in the basic reserves. For others, the impact of the discovery factor is slight. The nature and relative continuity of coal beds, for example, is such that the discovery of large, new, unknown reserves of coal is unlikely in any country that has been even moderately well explored. In areas of complex geologic structure, however, where relatively little mining or drilling has been done, new discoveries may be made even of coal. For example, in England, during drilling for oil in World War II, large, new, hitherto unknown deposits of coal were discovered. In this country little change in our basic reserves of coal will result from new discoveries. Some possibilities for such discoveries still exist, however, in a few regions, such as the Pennsylvania anthracite fields and the overthrust belts of western Montana.

2. By accessions of geologic data where general geologic evidence indicates that the substance may be present in substantial amounts,

but where quantitative data are not available on which to base a sound computation of the actual amount. For coal, this factor is very substantial in this country, where large areas that are known to be coal bearing are inadequately mapped. In preparation of a new reserve estimate of Wyoming, for example, recently published by the United States Geological Survey, no estimate could be made for 53 percent of the area of the State known to be underlaid by coal-bearing rocks.

3. By large unforeseen technologic changes that substantially affect the fundamental assumptions as to what kinds of occurrences should be included. The discovery, for example, of the profitable extractability of magnesium from sea water introduced an entirely new and fundamental concept into appraisals of magnesium reserves.

Computations of basic reserves, then, are subject to revision and change in three principal ways. But when compared with "recoverable reserves" they are relatively stable. Obviously, not all the reserves computed as "basic reserves" can ordinarily be extracted for use. Recoverability of the basic reserve depending on conditions and on the substance involved may range from a very low percentage to almost 100 percent. Recoverability depends on the efficiency of extraction methods or production techniques, on restrictions imposed on underground removal methods by the need for protection of surface or subsurface installations, and on economic incentives for production. Recoverability, and hence "recoverable reserves" thus differ from date to date and change almost constantly.

In any attempt to make quantitative comparisons of fuel reserves, it must be borne in mind that the widely varying modes of occurrence of mineral fuels and the different methods of extraction produce great differences in the commonly cited reserve figures. Virtually no data on the ultimately expectable size of basic reserves of petroleum and natural gas have been assembled. As will be explained more fully in the appropriate place, the basic reserves of these fuels are subject to continuing large, relatively unpredictable increases through new discoveries, and estimates of petroleum and natural gas yet to be discovered cannot be more than crudely qualitative. For coal the order of magnitude of our basic reserves has been approximated. They could be determined with close approach to accuracy by obtaining the complete geologic and exploratory data required. Recoverability of coal reserves, on the other hand, is subject to the impact of rapidly changing mining technology which may increase our reserves as the result of higher rates of recovery.

From the foregoing, it is clear that the mathematical expression of reserves is meaningful only in the light of the assumptions on which the appraisal is based. In the succeeding analyses of the present state of knowledge of our national fuel reserves it is hoped that these conditions are fully and accurately stated, and that in conclusion some valid comparisons may be drawn.

Coal Reserves

HISTORY

The first estimates of the total coal reserves of the United States were prepared by M. R. Campbell of the Geological Survey, and

published at various times in the period prior to 1929.[2] In the years following 1929 the Campbell estimate was republished with only minor modifications by a number of individuals and organizations, and it has received wide circulation in the literature devoted to discussions of fuels reserves.[3] Campbell's estimates were necessarily based on many assumptions concerning the thickness and lateral extent of coal beds in areas for which little geologic data were then available. Also, he included in his estimates all coal in beds more than 14 inches thick under less than 3,000 feet of overburden, without attempting to distinguish between reserves of thick, easily accessible coal and reserves of thin, deeply buried coal. Such an inclusive estimate has only general usefulness.

In the period 1928 to 1947 reappraisals of the coal reserves in Pennsylvania, West Virginia, Illinois, and Kansas were prepared by the geological surveys of those States.[4] These estimates were marked improvements over the earlier estimates.

Growing awareness of the depletion of all our resources accelerated by the extraordinary demands of the Second World War has led in recent years to renewed interest in the quantity of coal, heretofore considered to be so abundant as to occasion no concern for the future. As part of this generally expanded interest, the United States Geological Survey in 1947 began a program to reappraise the coal reserves of the United States in which primary emphasis is being placed on the amounts of coal in separate categories according to rank, thickness of coal, thickness of overburden, and relative abundance of reliable data available for making the estimates. Prepared as part of this program to date are summary reappraisals of the coal reserves of Michigan, Montana, New Mexico, North Carolina, and Wyoming.[5]

Similarly, the United States Bureau of Mines has begun in recent years a program for the appraisal of the minable reserves of coking coal in the United States. The first report, covering reserves of coking coal in Cambria County, Pa., was published in 1950.[6]

The task of reappraising the Nation's coal resources is, however, far from being complete, and much additional work remains to be done.

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[2] Campbell, M. R., The Coal Fields of the United States, General Introduction: U. S. Geological Survey, Professional Paper 100, 1917 (1929).
Coal Resources of the United States, U. S. Geological Survey press release, 1929.

[3] Hendricks, T. A., Energy Resources and National Policy: Rept. of Energy Resources Committee to National Resources Committee, 76th Cong., 1st sess., H. Doc. 160, pp. 281–286, January 1939.
Buch, J. W., Hendricks, T. A., and Toenges, A. L., Coal, in Mineral Position of the United States: Hearings before a subcommittee of the Committee on Public Lands, U. S. Senate, 80th Cong., 1st sess., pp. 231–235, May 15, 16, and 20, 1947.

[4] Reese, John F., and Sisler, James D., Bituminous Coal Fields of Pennsylvania, Coal Resources: Pennsylvania Topographic and Geologic Survey, Bull. M–6, pt. 3, 1928.
Headlee, A. J., and Nolting, J. P., Characteristics of Minable Coal of West Virginia: West Virginia Geological Survey, vol. 13, 1940.
Cady, G. H., Content, Conduct, and Results of Illinois Coal Resources Inventories: Illinois Coal Research Conference, October 23–24, 1946.
Abernathy, G. E., Jewett, J. M., and Schoewe, W. H., Coal Reserves in Kansas: State Geological Survey of Kansas, Bull. 70, pt. 1, 1947.

[5] Cohee, G. V., Burns, R. N., Brown, Andrew, Brant, R. A., and Wright, Dorothy, Coal Resources of Michigan: U. S. Geological Survey Circular 77, 1950.
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Berryhill, H. L., Jr., Brown, D. M., Brown, Andrew, and Taylor, D. A., Coal Resources of Wyoming: U. S. Geological Survey Circular 81, 1950.

[6] Dowd, J. J., Turnbull, L. A., Toenges, A. L., Cooper, H. M., Abernethy, R. F., Reynolds, D. A., and Fraser, Thomas, Estimate of Known Recoverable Reserves of Coking Coal in Cambria County, Pa.: U. S. Bureau of Mines Report of Investigations 4734, 1950.

METHODS OF PREPARING ESTIMATES

Estimates of coal reserves, like those of other mineral resources, must be based on a series of assumptions in addition to the facts available from geologic observations, mining, and drilling. Because estimates of the tonnage of coal within individual areas tend to vary greatly, depending upon the assumptions and procedures used in preparing the estimates, an estimate of coal reserves has meaning only when considered in relation to the procedure followed in obtaining it.

For practical purposes, two cut-off points must be established in calculating coal reserves—one at the minimum thickness of coal included in the estimate, and another at the maximum thickness of overburden allowed above the coal. To date, however, no opinion is generally accepted as to the figures representing practical limits for the thickness of coal beds and of overburden. A very conservative estimate may include only the original reserves in thick beds and under slight overburden—in other words, reserves that could be recovered profitably under current mining conditions. A more inclusive estimate, on the other hand, may consider thinner, more impure, and more deeply buried coal as recoverable by improved methods when more easily mined deposits have been exhausted.

Other factors, in addition to those involving thickness of coal beds and of overburden, have to be established in calculating coal reserve estimates. The weight or specific gravity of the coal must be determined or assumed, and the method of estimating the amount of coal underground at a distance from an outcrop, mine, or drill hole must be selected. Again, these factors vary with estimates by different individuals, and the tonnages of coal in the estimates vary accordingly.

The United States Geological Survey, in order to produce uniformity of thinking and procedure on the part of Survey coal geologists, has adopted a set of procedures to be used in the calculation of coal reserves. Estimates of coal reserves thus obtained can easily be combined in county, State, and National totals of comparable value.

These procedures, which were prepared jointly by members of the Geological Survey and the Bureau of Mines, and include recommendations of the National Bituminous Coal Advisory Council, are discussed in paragraphs below.

Thickness of beds.—Coal reserves are calculated and reported by beds in categories of thickness as follows:

Anthracite, semianthracite, and bituminous coal:
- More than 42 inches.
- 28 to 42 inches.
- 14 to 28 inches.

Subbituminous coal and lignite:
- More than 10 feet.
- 5 to 10 feet.
- 2½ to 5 feet.

The thickness of a coal bed is evaluated wherever possible by the use of lines of equal thickness. Generally, however, the data are insufficient for this purpose, and average figures, which are weighted according to the approximate area of bed represented by each observation, must be used. If the points of observation are not evenly spaced, the weighting is accomplished by assigning intermediate values for the thickness at places where data are needed to fill out a system of evenly

spaced points. Where this procedure is followed to obtain the weighted average thickness along the outcrop of a persistent bed, the two end points of minimum thickness are also included in the average. Where the points of observation are fairly evenly spaced, as in an exploratory or development drilling program, a simple average is sufficient.

Partings more than three-eighths inch in thickness are omitted in determining the thickness of individual beds. Beds and parts of beds made up of alternating thin layers of coal and parting are omitted if the partings make up more than one-half the total thickness, or if the ash content exceeds 33 percent. Benches of coal of less than the minimum thicknesses stated above, which lie above or below thick partings, and which normally would be left in mining are also omitted.

Areal extent of beds.—The areal extent of coal beds included in reserve estimates may be determined in several ways. Where the continuity of the bed is well established by maps of the outcrop, mine workings, and drill holes, the entire area of known occurrence is used even though points of observation are widely spaced. Persistent beds that have been traced around a basin or spur are considered to underlie the area enclosed by the outcrop. Otherwise, the length of outcrop within the thickness limits listed above is considered to establish the presence of coal in a semicircular area having a radius equal to one-half the length of the outcrop. The total area of coal is considered to extend beyond such a semicircle if mine workings or drill holes so indicate; in which case coal is considered to extend not more than 1 mile beyond the limits of the mine workings. An isolated drill hole too far removed to be incorporated in the area thus defined is considered to determine the area of coal extending for a maximum radius of one-half mile around the hole.

Overburden.—Reserve data are also reported by the United States Geological Survey in the following classifications according to thickness of overburden:

0 to 1,000 feet.
1,000 to 2,000 feet.
2,000 to 3,000 feet.

Measured, indicated, and inferred reserves.—On the basis of the reliability of the data on which the calculations are based, coal reserves are reported in three classes, known as measured, indicated, and inferred. Measured coal is coal for which tonnage is computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced, and the thickness and extent of the coal are so well defined that the computed tonnage is judged to be accurate within 20 percent or less of the true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of coal varies in different regions according to the habit of the coal beds, the points of observation are, in general, of the order of one-half mile apart.

Indicated coal is coal for which tonnage is computed partly from specific measurements, and partly from projection of visible data for a reasonable distance on geologic evidence. In general, the points of observation are of the order of 1 mile apart, but may be as much as 1½ miles apart for beds of known geologic continuity.

Inferred coal is coal for which quantitative estimates are based largely on broad knowledge of the geologic character of the bed, or

region, and for which there are few, if any, measurements. The estimates are based on an assumed continuity for which there is geologic evidence. In general, inferred coal lies more than 2 miles from the outcrop.

Weight of coal.—Where precise data are not available, the following values are assigned as the weight of coal in all United States Geological Survey calculations of coal reserves:

	Tons per acre-foot
Anthracite and semianthracite	2,000
Bituminous coal	1,800
Subbituminous coal	1,770
Lignite	1,750

Original, remaining, and recoverable reserves.—Coal reserves are further classified as original reserves, remaining reserves, and recoverable reserves. Original reserves are the reserves of coal in the ground before the beginning of mining operations. In the calculation of original reserves no allowance is made for past production and losses in mining or for future losses. Remaining reserves are the reserves in the ground as of the date of appraisal, and are obtained by subtracting past production and losses from original reserves. Recoverable reserves are reserves of coal in the ground as of the date of appraisal that can actually be produced in the future by current technologic processes, and are obtained by subtracting estimated future losses in mining from the remaining reserves.

The preparation of an estimate of original reserves is essential to the successful determination of remaining and recoverable reserves, because the figure provides a basis from which other data can be derived with ease. An estimate of original reserves, although subject to change with new mapping and exploration, is essentially a constant, needing no date or explanation to make it understandable. From this estimate the figures for remaining and recoverable reserves, which must be dated, can be determined annually, if desired, from available information on production, and losses, or from surveys of mined-out areas.

The only instance in which coal reserves can be calculated successfully without reference to original reserves is in virtually mined-out areas where remaining reserves are very small and clearly defined. In most coal areas in the United States, however, the remaining reserves still closely approximate the original reserves. This is particularly true in the West where little mining has been done.

PRESENT STATUS OF BASIC DATA

All estimates of coal reserves are based largely on detailed geologic maps showing the outcrops and correlations of the individual coal beds, and on accompanying geologic reports giving detailed measurements of the coal thickness. This information is augmented locally by data from exploratory and development drilling and from mines. Unfortunately, many coal-bearing areas in the United States have not been mapped geologically; many others have been mapped only in reconnaissance; and few have been prospected other than along the outcrops of the beds.

In preparing the estimate of Montana coal reserves presented in United States Geological Survey Circular 53, for example, it was necessary to omit approximately 10 percent of the total coal-bearing

land in the State, because in northeastern Montana the rocks are concealed by glacial drift and little or no detailed geologic information on the presence of coal beds was available. Similarly, the estimate for Wyoming represents only part of the reserves in the State; 53 percent of the total coal-bearing land in Wyoming was omitted from the estimate of Wyoming reserves contained in United States Geological Survey Circular 81, because of the scarcity of geologic data available for use in reserve calculations.

Even larger areas were omitted in Michigan where the coal occurs sporadically in isolated beds that vary greatly in thickness and generally pinch out within relatively short distances. As a result, satisfactory estimates of the extent and average thickness are possible only for relatively small areas, and in preparing the estimate of Michigan reserves presented in United States Geological Survey Circular 77, no areas were considered except those few having test-hole information.

Even in the eastern coal fields where information is generally considered to be more abundant, much of the geologic mapping of many years ago does not provide the data necessary for a modern inventory of reserves. Progress toward full knowledge of the coal reserves of the United States depends, therefore, upon an active program of detailed geologic mapping and exploratory drilling. Such detailed work is in progress on a modest scale by the United States Geological Survey, and by several State agencies.

PRESENT STATUS OF KNOWLEDGE OF RESERVES

A new coal reserve estimate for the United States as of January 1, 1950, has been prepared by the United States Geological Survey and is shown in tables 1 and 2, which give the reserve figures by State and by rank of coal.[7]

TABLE 1.—*Coal reserves of the United States, Jan. 1, 1950, by rank*

BITUMINOUS COAL

[In thousands of short tons]

State	Estimated original reserves	Reserves depleted to Jan. 1, 1950		Remaining reserves, Jan. 1, 1950	Recoverable reserves, Jan. 1, 1950, assuming 50 percent recovery
		Produced [1]	Produced and lost in mining, assuming past losses equal production		
Alabama	67,570,000	821,590	1,643,180	65,926,820	32,963,410
Arkansas	1,396,000	82,785	165,570	1,230,430	615,215
Colorado	213,071,000	357,719	715,438	212,355,562	106,177,781
Georgia	933,000	11,533	23,066	909,934	454,967
Illinois	171,905,000	3,131,997	6,263,994	165,641,006	82,820,503
Indiana	53,051,000	984,137	1,968,274	51,082,726	25,541,363
Iowa	29,160,000	343,162	686,324	28,473,676	14,236,838
Kansas	[3] 17,574,000	[3] 9,800	[3] 19,600	17,554,400	8,777,200
Kentucky	123,327,000	1,951,803	3,903,606	119,423,394	59,711,697
Maryland	8,043,000	259,943	519,886	7,523,114	3,761,557
Michigan	296,900	[4] 46,240	[5] 77,000	219,900	109,950
Missouri	79,362,016	257,787	515,574	78,846,442	39,423,221
Montana	2,362,610	31,491	62,982	2,299,628	1,149,814
New Mexico	10,947,700	88,189	176,378	10,771,322	5,385,661

See footnotes at end of table, p. 9.

[7] Averitt, Paul, and Berryhill, L. R., Coal Resources of the United States, a Progress Report, November 1, 1950: U. S. Geological Survey Circular 94, 1950.

TABLE 1.—*Coal reserves of the United States, Jan. 1, 1950, by rank*—Continued

BITUMINOUS COAL—Continued

[In thousands of short tons]

State	Estimated original reserves	Reserves depleted to Jan. 1, 1950		Remaining reserves, Jan. 1, 1950	Recoverable reserves, Jan. 1, 1950, assuming 50 percent recovery
		Produced [1]	Produced and lost in mining, assuming past losses equal production		
North Carolina	110,462	1,054	2,108	108,354	54,177
Ohio	86,497,000	1,694,259	3,388,518	83,108,482	41,554,241
Oklahoma	54,951,000	158,846	317,692	54,633,308	27,316,654
Pennsylvania	75,093,459	7,416,956	14,833,912	60,259,547	30,129,774
Tennessee	25,665,000	324,718	649,436	25,015,564	12,507,782
Texas	8,000,000	10,706	21,412	7,978,588	3,989,294
Utah	88,184,000	195,833	391,666	87,792,334	43,896,167
Virginia	21,149,000	538,887	1,077,774	20,071,226	10,035,613
Washington	11,413,000	123,804	247,608	11,165,392	5,582,696
West Virginia	116,618,447	4,979,385	9,958,770	106,659,677	53,329,838
Wyoming [6]	13,234,950	230,272	460,544	12,774,406	6,387,203
Other States [7]	820,000	4,956	9,912	810,088	405,044
Total	1,280,735,544	24,057,852	48,100,224	1,232,635,320	616,317,660
SUBBITUMINOUS COAL					
Colorado	104,175,000	107,506	215,012	103,959,988	51,979,994
Montana	132,151,060	124,544	249,088	131,901,972	65,950,986
New Mexico	50,801,200	32,226	64,452	50,736,748	25,368,374
Utah	5,156,000	2,832	5,664	5,150,336	2,575,168
Washington	52,442,000	19,100	38,200	52,403,800	26,201,900
Wyoming [6 8]	108,318,900	132,103	264,206	108,054,694	54,027,347
Other States [9]	15,500,000	3,832	7,664	15,492,336	7,746,168
Total	468,544,160	422,143	844,286	467,699,874	233,849,937
LIGNITE					
Arkansas	90,000	0	0	90,000	45,000
Montana [6]	87,533,270	1,213	2,426	87,530,844	43,765,422
North Dakota	600,000,000	67,856	135,712	599,864,288	299,932,144
South Dakota	1,020,000	921	1,842	1,018,158	509,079
Texas	23,000,000	51,341	102,682	22,897,318	11,448,659
Wyoming					
Other States [10]	49,963	1	2	49,961	24,981
Total	711,693,233	121,332	242,664	711,450,569	355,725,285
ANTHRACITE AND SEMIANTHRACITE					
Arkansas	230,000	9,109	18,218	211,782	105,891
Colorado	100,000	5,921	11,842	88,158	44,079
New Mexico	5,700	1,092	2,184	3,516	1,758
Pennsylvania	22,805,000	4,916,006	9,832,012	12,972,988	6,486,494
Virginia	500,000	9,592	19,184	480,816	240,408
Washington	23,000	0	0	23,000	11,500
Total	23,663,700	4,941,720	9,883,440	13,780,260	6,890,130
Total, all ranks	2,484,636,637	29,543,047	59,070,614	2,425,566,023	1,212,783,012

[1] Production, 1800 through 1885, from The First Century and a Quarter of American Coal Industry, by H. N. Eavenson, privately printed, Pittsburgh, 1942; production, 1886 through 1949, from U. S. Bureau of Mines Minerals Yearbooks, unless otherwise indicated.

[2] Remaining reserves, Jan. 1, 1946.

[3] Production, Jan. 1, 1946, to Jan. 1, 1950.

[4] Michigan Geological Survey Division, as cited in U. S. Geological Survey Circular 77, p. 56, 1950.

[5] Past losses assumed to be 40 percent of coal originally in the ground.

[6] Ten percent of coal-bearing area in Montana, and 53 percent of coal-bearing area in Wyoming omitted from estimate.

[7] Includes Arizona, California, Idaho, and Oregon.

[8] Small reserves and production of lignite included under subbituminous coal.

[9] Includes Arizona, California, and Oregon.

[10] Includes California and Louisiana.

TABLE 2.—*Coal reserves of the United States, Jan. 1, 1950, by States*

[In thousands of short tons]

State	Estimated original reserves					Reserves depleted to Jan. 1, 1950		Remaining reserves, Jan. 1, 1950	Recoverable reserves, Jan. 1, 1950, assuming 50-percent recovery
	Bituminous coal	Subbituminous coal	Lignite	Anthracite and semi-anthracite	Total	Produced [1]	Produced and lost in mining, assuming past losses equal production		
Alabama	67,570,000				67,570,000	821,590	1,643,180	65,926,820	32,963,410
Arkansas	1,396,000		90,000	230,000	1,716,000	91,894	183,788	1,532,212	766,106
Colorado	213,071,000	104,175,000		100,000	317,346,000	471,146	942,292	316,403,708	158,201,854
Georgia	933,000				933,000	11,533	23,066	909,934	454,967
Illinois	171,905,000				171,905,000	3,131,997	6,263,994	165,641,006	82,820,503
Indiana	53,051,000				53,051,000	984,137	1,968,274	51,082,726	25,541,363
Iowa	29,160,000				29,160,000	343,162	686,324	28,473,676	14,236,838
Kansas	[2] 17,574,000				[2] 17,574,000	[3] 9,800	[3] 19,600	17,554,400	8,777,200
Kentucky	123,327,000				123,327,000	1,951,803	3,903,606	119,423,394	59,711,697
Maryland	8,043,000				8,043,000	259,943	519,886	7,523,114	3,761,557
Michigan	296,900				296,900	[4] 46,240	[5] 77,000	219,900	109,950
Missouri	79,362,016				79,362,016	257,787	515,574	78,846,442	39,423,221
Montana	[10] 2,362,610	132,151,060	87,533,270		222,046,940	157,248	314,496	221,732,444	110,866,222
New Mexico	10,947,700	50,801,200		5,700	61,754,600	121,507	243,014	61,511,586	30,755,793
North Carolina	110,462				110,462	1,054	2,108	108,354	54,177
North Dakota			600,000,000		600,000,000	67,856	135,712	599,864,288	299,932,144
Ohio	86,497,000				86,497,000	1,694,259	3,388,518	83,108,482	41,554,241
Oklahoma	54,951,000				54,951,000	158,846	317,692	54,633,308	27,316,654
Pennsylvania	75,093,459			22,805,000	97,898,459	12,332,962	24,665,924	73,232,535	36,616,268
South Dakota			1,020,000		1,020,000	921	1,842	1,018,158	509,079
Tennessee	25,665,000				25,665,000	324,718	649,436	25,015,564	12,507,782
Texas	8,000,000		23,000,000		31,000,000	62,047	124,094	30,875,906	15,437,953
Utah	88,184,000	5,156,000			93,340,000	198,665	397,330	92,942,670	46,471,335
Virginia	21,149,000			500,000	21,649,000	548,479	1,096,958	20,552,042	10,276,021
Washington	11,413,000	52,442,000		23,000	63,878,000	142,904	285,808	63,592,192	31,796,096
West Virginia	116,618,447				116,618,447	4,979,385	9,958,770	106,659,677	53,329,838
Wyoming	[10] 13,234,950	[6] 108,318,900	([6])		121,553,850	362,375	724,750	120,829,100	60,414,550
Other States	[7] 820,000	[8] 15,500,000	[9] 49,963		16,369,963	8,789	17,578	16,352,385	8,176,193
Total	1,230,735,544	468,544,160	711,693,233	23,663,700	2,484,636,637	29,543,047	59,070,614	2,425,566,023	1,212,783,012

[1] Production, 1800 through 1885, from The First Century and a Quarter of American Coal Industry, by H. N. Eavenson, privately printed, 1942; production, 1886 through 1949, from U. S. Bureau of Mines Minerals Yearbooks, unless otherwise indicated.

[2] Remaining reserves, Jan. 1, 1946.

[3] Production, Jan. 1, 1946, to Jan. 1, 1950.

[4] Michigan Geological Survey Division, as cited in U. S. Geological Survey Circular 77, p. 56, 1950.

[5] Past losses assumed to be 40 percent of coal originally in the ground.

[6] Small reserves of lignite included under subbituminous coal.

[7] Includes Arizona, California, Idaho, and Oregon.

[8] Includes Arizona, California, and Oregon.

[9] Includes California and Louisiana.

[10] 10 percent of coal-bearing area in Montana, and 53 percent of coal-bearing area in Wyoming omitted from estimate.

The 1950 estimate incorporates the new estimates for Michigan, North Carolina, New Mexico, Montana, and Wyoming recently published by the United States Geological Survey, and the new estimates for Kansas, Illinois, and West Virginia published by the respective State surveys. It also includes State survey estimates for the coal reserves of Pennsylvania and Missouri which were published many years ago, but which are the best estimates available for those States.[8] The estimate for Ohio appearing in tables 1 and 2 is that published by the United States Geological Survey in 1918, with modifications to accord with a recent estimate for the coal reserves of Perry County.[9]

For the remaining States in which little or no summary work on coal reserves has been carried on, the estimates used in tables 1 and 2 are those of Campbell.

Because the methods employed in preparing appraisals of reserves in some of the States were markedly different from those used in preparing appraisals of reserves in other States, it is recognized that the individual State estimates are not entirely comparable. No attempt was made, however, in assembling tables 1 and 2 in this report to introduce arbitrary mathematical adjustment in the published figures. It was felt that the differences represented studied decisions by the appraisors, and were due probably to differences in the occurrence of the coal, amount of information available for making an appraisal, and other local factors not susceptible to simple mathematical adjustment. For a complete understanding of the significance of each of the figures in tables 1 and 2, a study of the methods used in preparing the estimates is necessary. Even the recent United States Geological Survey estimates for various States were prepared by slightly different methods, though in general the procedures followed were those already described in this report. A summary of the methods used in preparing each of the individual State estimates shown in the tables is contained in United States Geological Survey Circular 94.

The geographic distribution of the coal reserves presented in tables 1 and 2 is shown in the accompanying maps (figs. 1 and 2), which also show the very unequal distribution of coal according to rank. Approximately 30 percent of the total coal reserves of the United States occur east of the Mississippi River, yet this area contains 60 percent of the total reserves of bituminous and anthracite coal. The coal-bearing States west of the Mississippi River contain 70 percent of the total reserves of the Nation, but most of the coal is of lignite, subbituminous, or high-volatile bituminous rank. Reserves of medium-volatile bituminous coal occur in Iowa, Kansas, and Oklahoma, and reserves of low-volatile bituminous coal in Oklahoma and Arkansas, but west of these States, coal of medium- and low-volatile bituminous ranks occurs only in local deposits.

[8] Reese, J. F., and Sisler, J. D., Bituminous Coal Fields of Pennsylvania: Pennsylvania Topographic and Geologic Survey, Bull. M 6, pt. 3, Coal resources, pp. 1-9, 1928.
Ashley, G. H., Anthracite Reserves: Pennsylvania Topographic and Geologic Survey Progress Report 130, 1945.
Hinds, Henry, The Coal Deposits of Missouri: Missouri Bureau of Geology and Mines, 2d ser., vol. 11, 1913.

[9] Clark, F. R., Original Coal Content of the Fields, in Bownocker, J. A., The Coal Fields of Ohio: U. S. Geological Survey Professional Paper 100, pp. 88-96, 1918 (1929).
Flint, N. K., The Coal Reserves of Perry County, Ohio: Paper presented at Columbus meeting of Am. Inst. Min. Met. Eng., September 1949.

80424—51——3

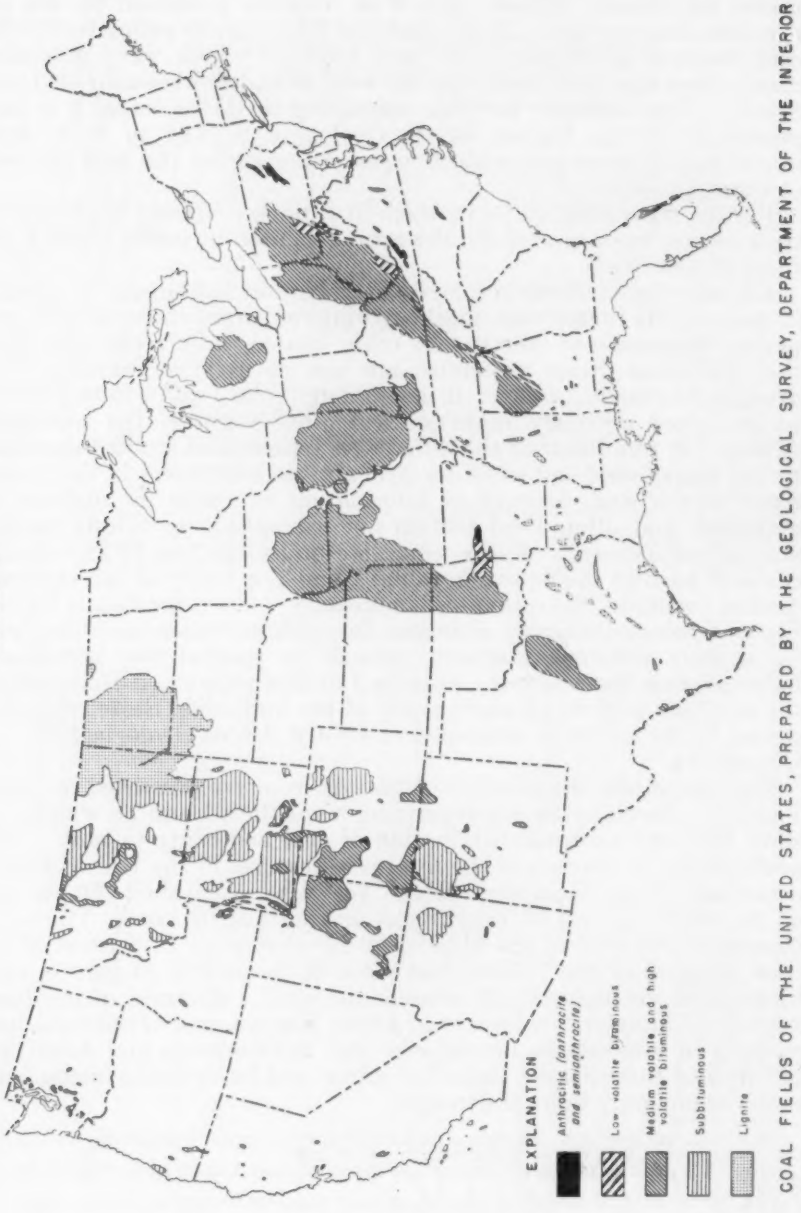

EXPLANATION
Anthracite (anthracite and semianthracite)
Low volatile bituminous
Medium volatile and high volatile bituminous
Subbituminous
Lignite
COAL FIELDS OF THE UNITED STATES, PREPARED BY THE GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

FIGURE 1

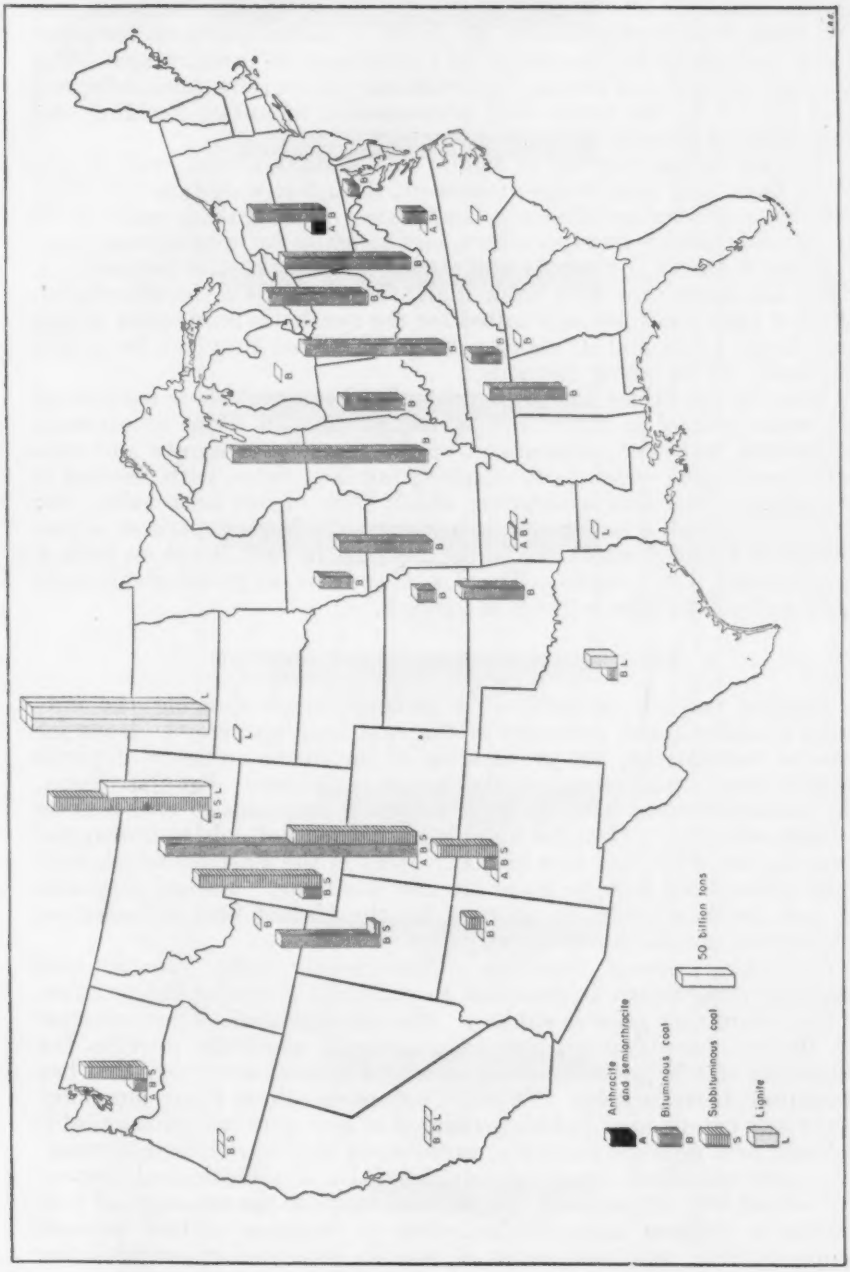


Figure 2. - Remaining coal reserves of the United States, January 1, 1950

This variation in rank of coal according to geographic distribution is principally the result of differences in age. Essentially all the coal in States east of the Mississippi River, and in Kansas, Iowa, Oklahoma, and Arkansas, is of Pennsylvanian age; in the Western States, on the other hand, essentially all the coal is of Cretaceous or Tertiary age. The younger western coal attains high rank only where it has been deformed and altered by the forces that accompanied mountain building and intrusions of igneous rock.

The far larger reserves of lignite and subbituminous coal in the West have only local value at present, though it is certain that they will have greater usefulness in the future. Coal of these ranks tends to crumble during transportation, and to ignite by spontaneous combustion if stored for too long a period without special precautions. They also have lower heat value than other coals. On the other hand, the low rank coals are well suited for the synthetic production of gas and liquid fuels, and in many parts of the West they can be mined efficiently by stripping methods.

Most of the tables and illustrations in this report show reserves of all ranks of coal in short tons as computed. In terms of ultimate usefulness, however, comparison of the reserves of lignite and subbituminous coal, which have relatively low heat value, with reserves of bituminous coal and anthracite, which have higher heat value, can best be made on a uniform B. t. u. basis. Such a comparison is presented in figure 4 which shows the reserves in each State on both a tonnage and B. t. u. basis. The B. t. u. content of typical coal in each rank and subdivision is given in figure 3.

RECOMMENDATIONS FOR FUTURE WORK

Detailed geologic mapping.—As geologic maps showing the outcrop, thickness, and structure of the coal beds provide the basis for reserve calculations, the preparation of improved estimates depends largely upon the increased availability of such data. For this reason, the continuation of basic geologic mapping programs in coal-bearing areas is essential. Detailed mapping is needed not only in unmapped areas in the West, but also in many areas in the East for which only older generalized geologic maps are now available. Modest programs of such work are now in progress by the United States Geological Survey and several State agencies.

Continuing reserve inventory.—Concurrently with the detailed mapping programs it is desirable to maintain a continuing program of State summary reserve studies. These reappraisals of coal reserves by States, based on information currently available provide the beginning of a framework of maintaining a current inventory that has heretofore been lacking. Properly organized, these State summary appraisals can be modified and enlarged as new data become available through new geologic mapping, exploratory drilling, or development. The new appraisals recently completed by the Geological Survey and others now in progress, are planned to show the tonnages of coal present in various categories according to thickness of bed, amount of overburden, and abundance of reliable information available for making the estimates. Because of the breakdown of data, the newer estimates are more significant and useful than older estimates, and having been calculated, can now be revised on the basis of any new

Figure 3

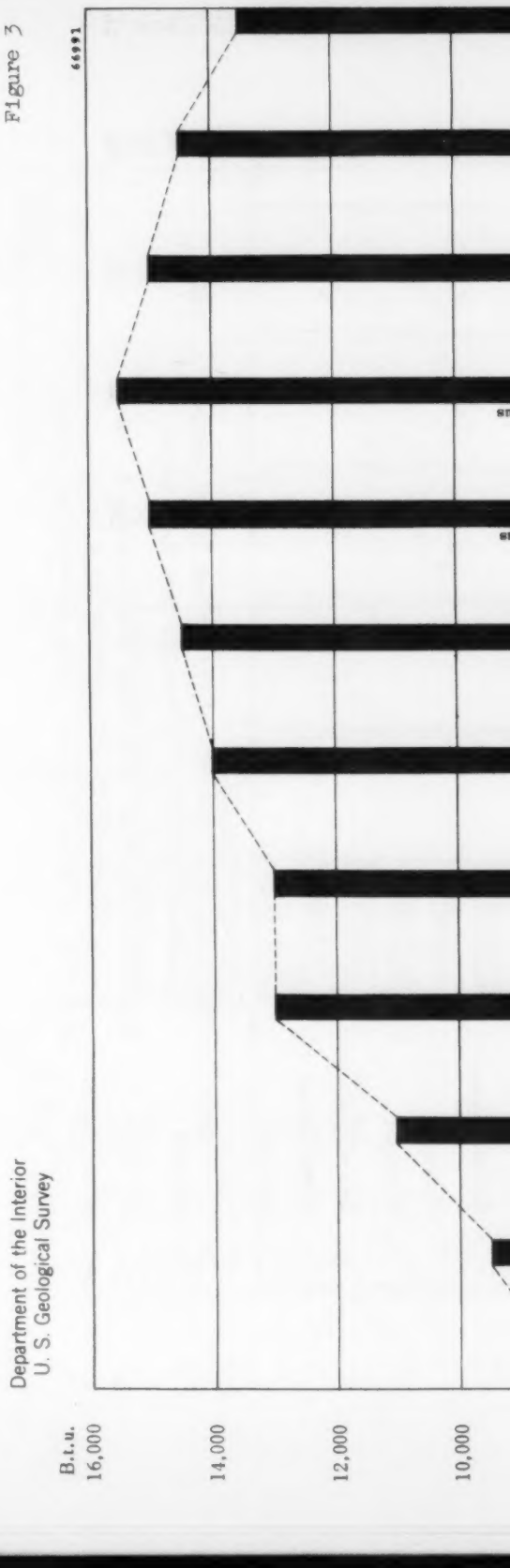
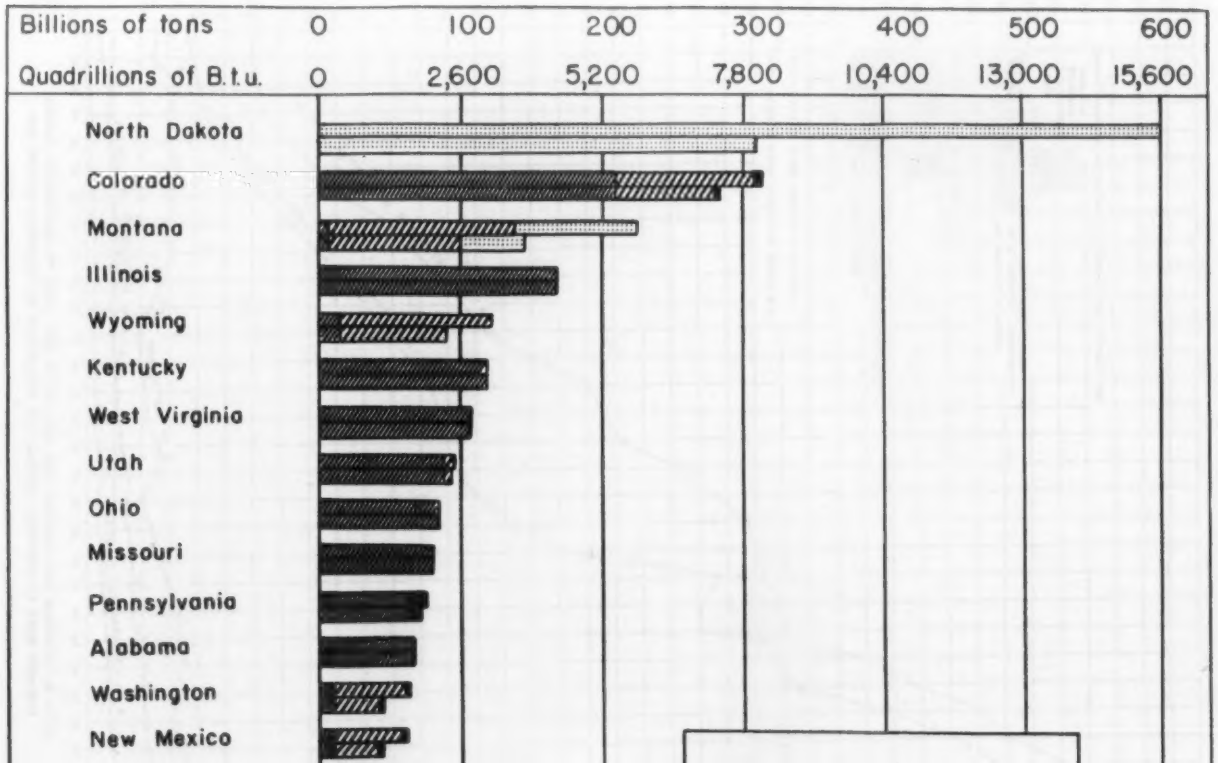


Figure 3. Heat value of coal of different ranks compared to proximate analyses

Upper diagram: Comparative heat value of typical samples of the several ranks of coal, computed on samples as received, on the ash-free basis. Lower diagram: Variation in the fixed carbon, volatile matter, and moisture of samples used in upper diagram, computed on samples as received, on the ash-free basis. (After: Coal fields of the United States, U. S. Geological Survey Prof. Paper 100, p. 8, 1929)

80424 O - 51 (Face p. 14) No. 1


Billions of tons
0
100
200
300
400
500
600
Quadrillions of B.t.u.
0
2,600
5,200
7,800
10,400
13,000
15,600
North Dakota
Colorado
Montana
Illinois
Wyoming
Kentucky
West Virginia
Utah
Ohio
Missouri
Pennsylvania
Alabama
Washington
New Mexico

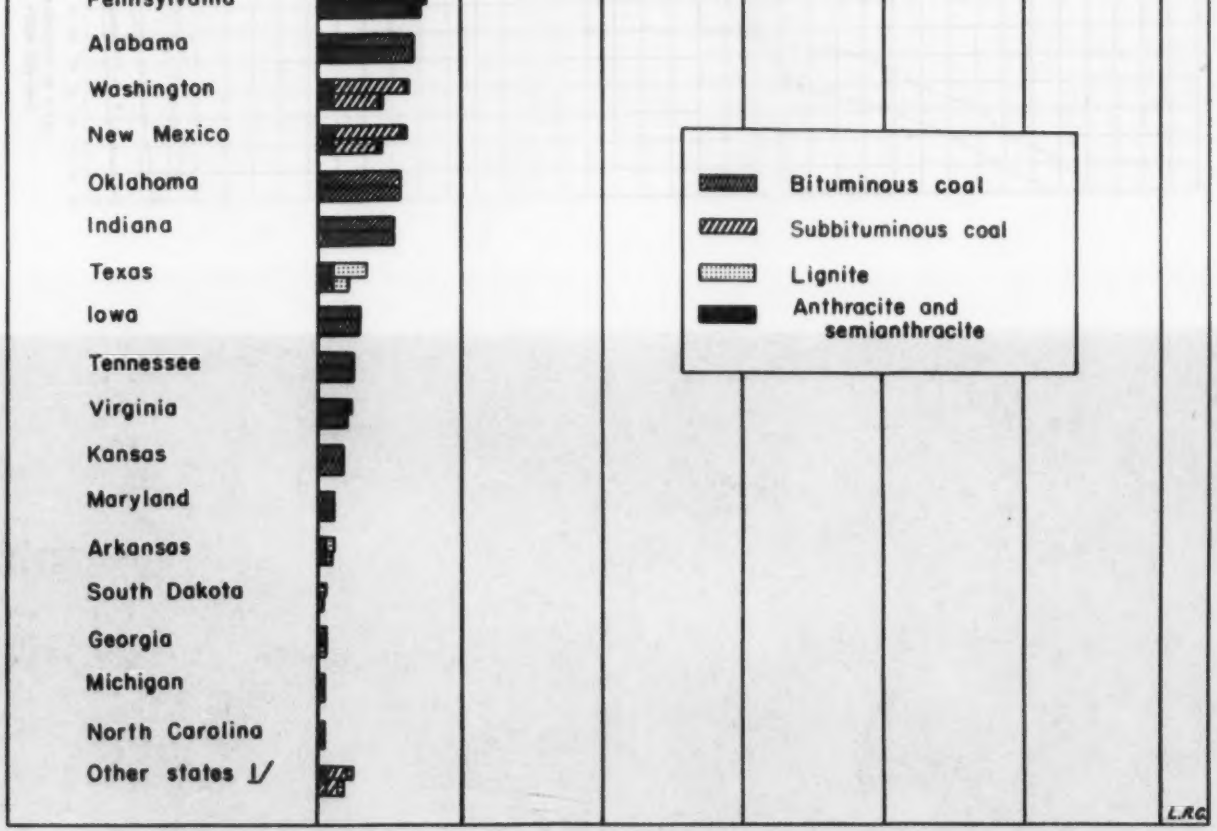


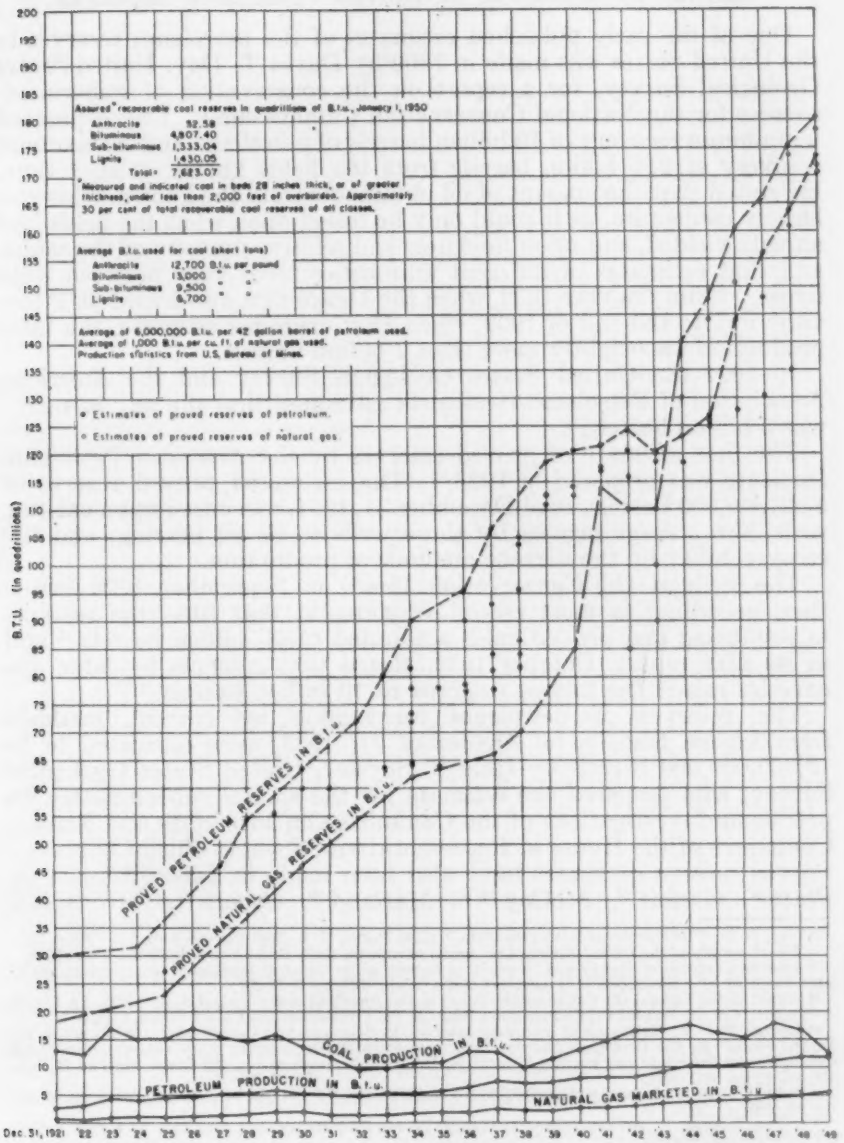
Figure 4. - Remaining coal reserves of the United States, January 1, 1950, by states according to tonnage and heat value

[Upper bar for each state shows coal reserves by tons; lower bar shows coal reserves by B.t.u.]

1/ Includes Arizona, California, Idaho, Louisana, and Oregon.

80424 O - 51 (Face p. 14) No. 2

FIGURE 5


Assured* recoverable coal reserves in quadrillions of B.t.u., January 1, 1950
Anthracite 52.58
Bituminous 4,807.40
Sub-bituminous 1,333.04
Lignite 1,430.05
Total 7,623.07
*Measured and indicated coal in beds 28 inches thick, or of greater thickness, under less than 2,000 feet of overburden. Approximately 30 per cent of total recoverable coal reserves of all classes.
Average B.t.u. used for coal (short tons)
Anthracite 12,700 B.t.u. per pound
Bituminous 13,000 " "
Sub-bituminous 9,500 " "
Lignite 6,700 " "
Average of 6,000,000 B.t.u. per 42 gallon barrel of petroleum used.
Average of 1,000 B.t.u. per cu. ft. of natural gas used.
Production statistics from U.S. Bureau of Mines.
o Estimates of proved reserves of petroleum.
o Estimates of proved reserves of natural gas.
B.T.U. (in quadrillions)
PROVED PETROLEUM RESERVES IN B.T.U.
PROVED NATURAL GAS RESERVES IN B.T.U.
COAL PRODUCTION IN B.T.U.
PETROLEUM PRODUCTION IN B.T.U.
NATURAL GAS MARKETED IN B.T.U.
Dec. 31, 1921 '22 '23 '24 '25 '26 '27 '28 '29 '30 '31 '32 '33 '34 '35 '36 '37 '38 '39 '40 '41 '42 '43 '44 '45 '46 '47 '48 '49

ANNUAL PRODUCTION OF COAL AND PETROLEUM, AND NATURAL GAS MARKETED IN B.T.U., AND PROVED RESERVES OF PETROLEUM AND NATURAL GAS IN B.T.U. FROM 1921-1949

data that become available. Such estimates will have continuing usefulness.

Petroleum and Natural Gas Reserves

HISTORY OF ESTIMATES OF PROVED PETROLEUM RESERVES

One of the early published estimates of the petroleum reserves in the United States was made in 1909 by David T. Day, United States Geological Survey, for a report on the conservation of mineral resources for the National Conservation Commission.[10] Day estimated a minimum recovery of 10 billion barrels of petroleum and a maximum recovery of 24½ billion barrels from the fields known at that time. He stated that the amount of oil obtainable from the known fields was largely conjecture, as it could only be based upon what the fields had already yielded, and upon thickness and relative porosity of the sands, and that estimates of different authorities must vary between wide limits. From the year 1859, when the Drake well was drilled at Titusville, Pa., to the end of 1909, when Day made his estimate, the total production was slightly more than 2 billion barrels.

In 1921 the United States Geological Survey and the American Association of Petroleum Geologists estimated that the oil "in sight" was 5 billion barrels.[11]

The first estimate of proved reserves by the American Petroleum Institute was prepared in 1925.[12] The estimated proved reserve of 5,321,427,000 barrels, as of December 31, 1924, was based upon existing wells, the acreage proved by those wells to be oil bearing, and the recoverability by the current methods of production.

The Federal Oil Conservation Board in September 1926 stated that, according to most recent estimates at that time, the reserves in producing and proven fields amounted to 4½ billion barrels [13] and in its fifth report, October 1932, stated that reserves by later discoveries raised the known reserves to 10 billion barrels.[14]

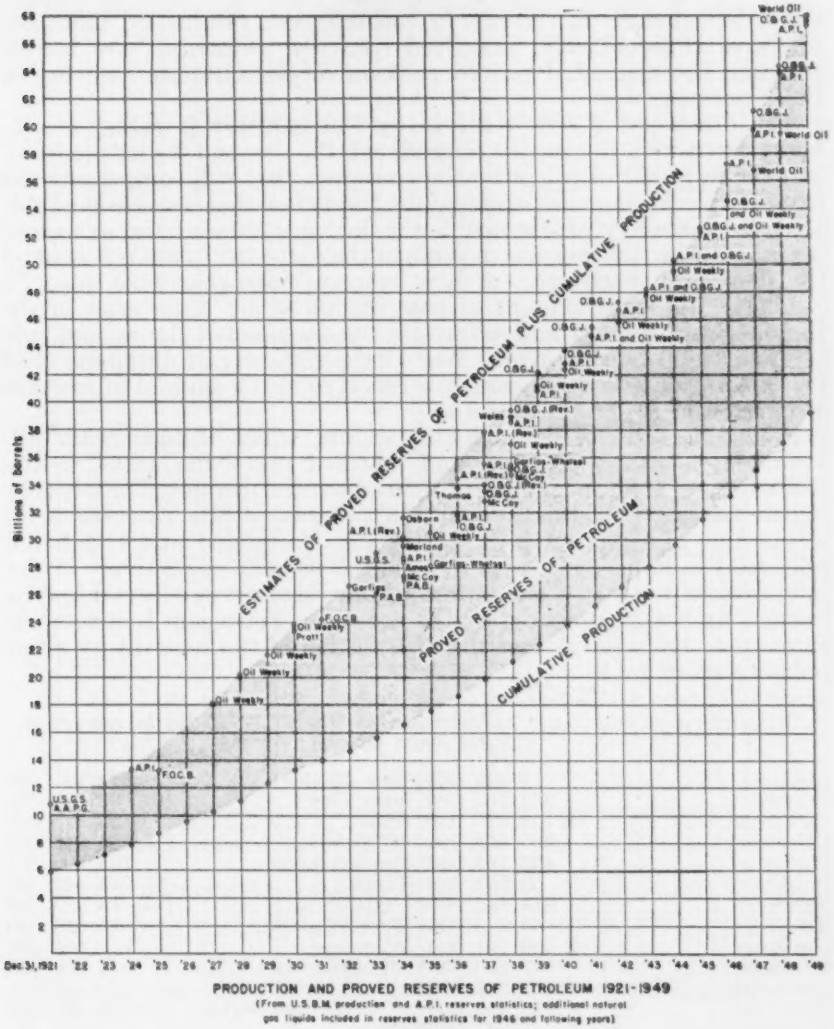
The reserves of petroleum recoverable by current methods from known fields as of December 31, 1933, were estimated to be 13,360,000,000 barrels by Hale B. Soyster, United States Geological Survey, who prepared the estimate for the special subcommittee on petroleum investigations of the Committee on Interstate and Foreign Commerce of the House of Representatives, Seventy-third Congress.[15] Proved reserve estimates have also been made in different years by Pratt [16], Garfias [17], McCoy [18 19], Marland [20], Osborn [21], Garfias and

[10] Day, D. T., The Petroleum Resources of the United States, U. S. Geol. Survey Bull. 394, 1909, p. 35.
[11] The oil supply of the United States, Am. Assoc. Petroleum Geol. Bull., Vol. 6, 1922, No. 1, pp. 42–46.
[12] American Petroleum Supply and Demand: A Report to the board of directors of the American Petroleum Institute by a committee of 11 members of the board, 1925, pp. 7, 58–59.
[13] Report of the Federal Oil Conservation Board to the President of the United States, 1926, Pt. 1, p. 8.
[14] Report V of the Federal Oil Conservation Board to the President of the United States, 1932, p. 7.
[15] Soyster, Hale B., Estimates of petroleum reserves, in "Geology and Occurrence of Petroleum in the United States" by the Geological Survey, Petroleum Investigation; hearing before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73d Cong., 1934, on H. Res. 441, pt. 2, pp. 1071–1081.
[16] Pratt, Wallace E., Industry Must Drill 20,000 Wells Yearly, Oil and Gas Jour., vol. 30, No. 9, pp. 19 and 102–103, July 16, 1931.
[17] Garfias, Valentin R., An Estimate of the World's Proven Oil Reserves, Am. Inst. Min. Met. Eng. Trans., vol. 103, 1933, pp. 352–354.
[18] Statement of Alex W. McCoy, Petroleum Investigations; hearing before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73d Cong., 1934, on H. Res. 441, pt. 3, pp. 1454–1458.
[19] Estimate by Alex W. McCoy, Oil Weekly, vol. 88, No. 8, Jan. 31, 1938, pp. 10–11.
[20] Statement of E. W. Marland, Petroleum Investigation; hearing before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73d Cong., 1934, on H. Res. 441, pt. 3, pp. 1439–1445.
[21] Statement of Campbell Osborn, Petroleum Investigation; hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, 73d Cong., 1934, on H. Res. 441, pt. 3 pp. 1458–1463.

Whetsel [22], and Thomas [23]. Also estimates have been published annually by the Oil Weekly, World Oil, and Oil and Gas Journal for a number of years (fig. 6).

For 1934, 1936, and each succeeding year the American Petroleum Institute, through its committee on petroleum reserves has prepared

FIGURE 6


ESTIMATES OF PROVED RESERVES OF PETROLEUM PLUS CUMULATIVE PRODUCTION
PROVED RESERVES OF PETROLEUM
CUMULATIVE PRODUCTION
Billions of barrels
Dec. 31, 1921
PRODUCTION AND PROVED RESERVES OF PETROLEUM 1921-1949
(From U.S.B.M. production and A.P.I. reserves statistics; additional natural gas liquids included in reserves statistics for 1946 and following years)

estimates of proved petroleum reserves of the United States which represent only the amount of crude oil recoverable under current economic and existing operating conditions from fields now completely developed or drilled or sufficiently drilled and explored to permit

[22] Garfias, V. R., and Whetsel, R. V., Proven Oil Reserves, Am. Inst. Min. Met. Eng. Trans., vol. 118, 1936, pp. 211–214.

[23] Thomas, J. Elmer, Proved Oil Reserves in United States of America, Am. Assoc. Petroleum Geol. Bull., vol. 21, 1937, No. 8, pp. 1088–1091.

reasonably accurate calculations. Up to and including its figures on proved reserves of petroleum as of December 31, 1945, the API estimates included cycle-plant and lease condensate but did not include all classes of natural-gas liquids. Beginning with the report for the year 1946 the estimates of the proved reserves included crude oil and the hydrocarbon liquids which are gaseous in the reservoir but may be reclaimed at the surface by condensation or absorption.

For each annual estimate of petroleum reserves it must be emphasized that changes in the rate of consumption, production practices, prices of crude oil, and improved recovery techniques, are factors affecting the estimated proved reserves or the ultimate recovery of those reserves.

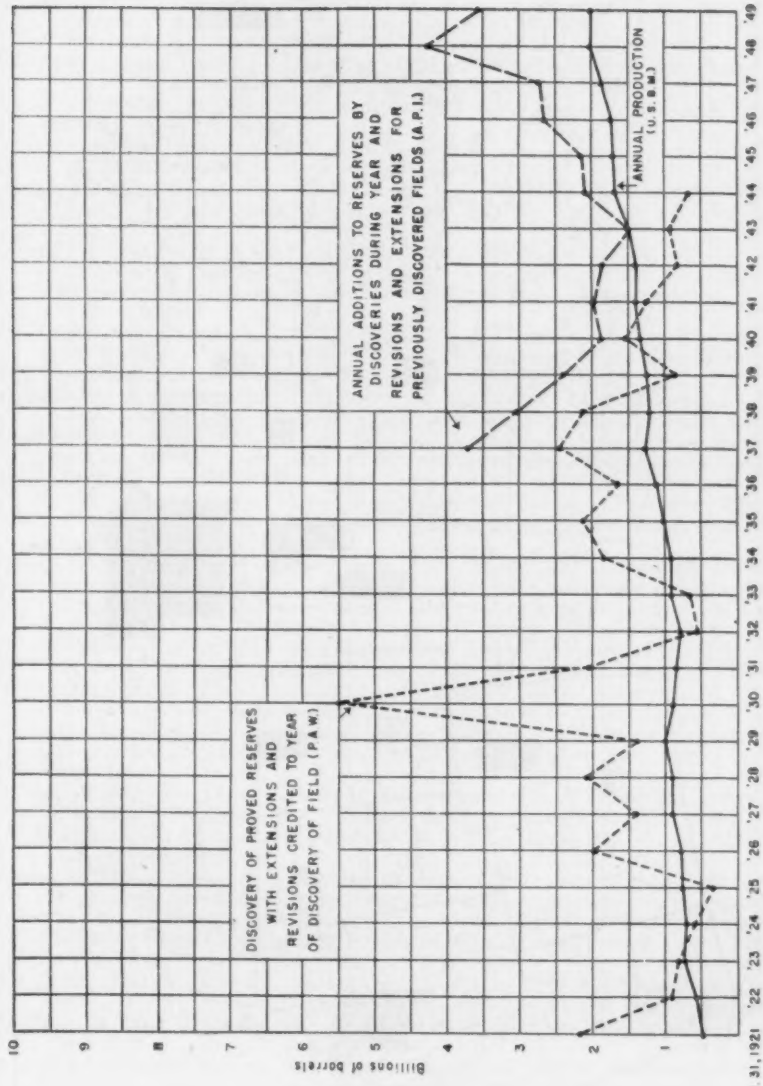
The discovery of new reserves by the industry is rather closely interrelated with the supply of crude oil, the demand for its products, and the payment of prices by the consumer that will compensate the cost of exploration. For example the flood of oil that became available after the discovery of the east Texas field in 1930 and the decreased demand during the depression years in the early 1930's are reflected by the decreased discoveries of new reserves following 1930 (fig. 7). Similarly the large amount of reserves added by discoveries in the Illinois Basin in 1937 and subsequent years affected the annual rate of discovery. During World War II the difficulty of obtaining steel for exploration and development is reflected in the amount of reserves discovered in 1943.

Proved reserves of liquid hydrocarbons, which include crude oil, condensate, natural gasoline, and liquefied petroleum gases, in the United States at the beginning of 1950 amounted to approximately 28.4 billion barrels. Of this amount 55 percent of the reserves is in Texas and 14.6 percent is in California. Louisiana and Oklahoma rank next in importance with 8.8 and 5.5 percent respectively of the total proved reserves. The estimated proved reserves of liquid hydrocarbons by States, prepared by the American Petroleum Institute, on January 1, 1950, follow and the distribution of the reserves by areas is shown on figure 8.

Estimated reserves of liquid hydrocarbons on Jan. 1, 1950 (in barrels of 42 United States gallons)

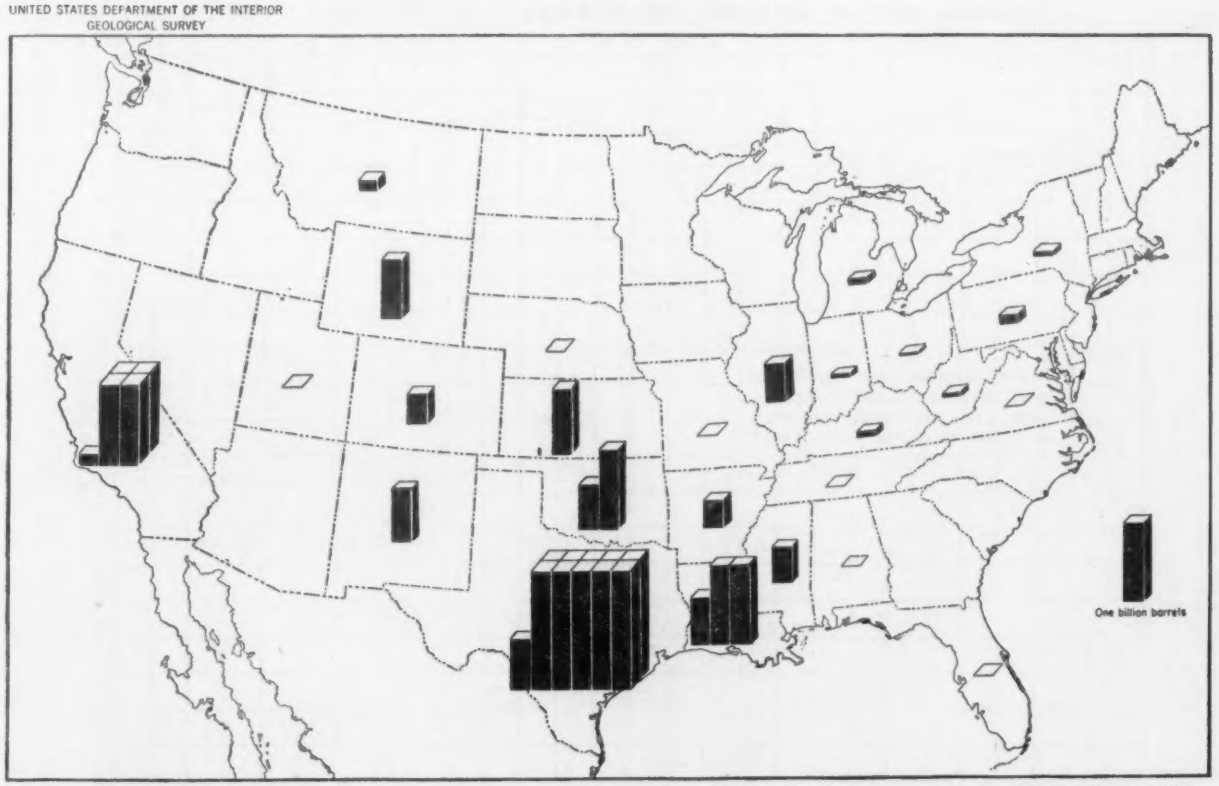
Alabama	3, 547, 000	New Mexico	677, 941, 000
Arkansas	353, 105, 000	New York	62, 900, 000
California	4, 143, 026, 000	Ohio	29, 373, 000
Colorado	369, 002, 000	Oklahoma	1, 563, 948, 000
Illinois	494, 804, 000	Pennsylvania	105, 999, 000
Indiana	50, 335, 000	Texas	15, 653, 443, 000
Kansas	844, 795, 000	Utah	16, 039, 000
Kentucky	69, 413, 000	West Virginia	50, 823, 000
Louisiana	2, 506, 191, 000	Wyoming	735, 465, 000
Michigan	67, 699, 000	Miscellaneous [1]	3, 659, 000
Mississippi	459, 267, 000		
Montana	116, 103, 000	United States	28, 378, 501, 000
Nebraska	1, 624, 000		

[1] Includes Alabama and New York natural gas liquids; Missouri, Tennessee, and Virginia crude oil; and Florida crude and natural gas liquids.


ANNUAL PRODUCTION OF PETROLEUM AND DISCOVERY OF NEW RESERVES
Billions of barrels
Dec. 31, 1921
DISCOVERY OF PROVED RESERVES WITH EXTENSIONS AND REVISIONS CREDITED TO YEAR OF DISCOVERY OF FIELD (P.A.W.)
ANNUAL ADDITIONS TO RESERVES BY DISCOVERIES DURING YEAR AND REVISIONS AND EXTENSIONS FOR PREVIOUSLY DISCOVERED FIELDS (A.P.I.)
ANNUAL PRODUCTION (U.S.B.M.)

80424—51——4

FIGURE 8



PROVED RESERVES OF LIQUID HYDROCARBONS IN THE UNITED STATES ON JANUARY 1, 1950 AS ESTIMATED BY THE AMERICAN PETROLEUM INSTITUTE

Estimates of petroleum reserves for years indicated in fig. 6

Year ending Dec. 31—

1921—5,000,000,000 barrels. Estimate by joint committee representing the American Association of Petroleum Geologists and the Geological Survey in the Oil Supply of the United States: American Association Petroleum Geologists Bulletin, volume 6, No. 1, pages 42–46, 1922.

1924—5,321,427,000 barrels. A report to the board of directors of the American Petroleum Institute by a committee of 11 members of the board in American Petroleum Supply and Demand, 1925.

1925—4,500,000,000 barrels. Report of the Federal Oil Conservation Board to the President of the United States, part 1, page 8, 1926.

1927—7,704,000,000 barrels. H. J. Struth, Oil Weekly, volume 65, No. 5, pages 16–18, April 18, 1932.

1928—9,071,000,000 barrels. H. J. Struth, idem.

1929—9,199,000,000 barrels. H. J. Struth, idem.

1930—10,000,000,000 barrels. W. E. Pratt, Industry Must Drill 20,000 Wells Yearly: Oil and Gas Journal, volume 30, No. 9, pages 19, 102–103, July 16, 1931.

1930—10,578,000,000 barrels. H. J. Struth, op. cit., pages 16–18.

1931—10,000,000,000 barrels, October 1932. Report V of the Federal Oil Conservation Board to the President of the United States, pages 7, 41, 1932.

1932—12,000,000,000 barrels. V. R. Garfias, An Estimate of the World's Proven Oil Reserves: American Institute of Mining and Metallurgical Engineers Transactions, volume 103, pages 352–354, 1933.

1933—10,638,000,000 barrels. Petroleum Administrative Board, Report on the Cost of Producing Petroleum, page 133, 1936 (issued December 1935).

1933—13,360,000,000 barrels. H. B. Soyster, Estimates of Petroleum Reserves, in Geology and Occurrence of Petroleum in the United States, by the Geological Survey: Petroleum Investigation: hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, on House Resolution 441, part 2, pages 1071–1081, 1934.

1934—10,700,000,000 barrels. Statement of A. W. McCoy: Petroleum Investigation: hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, on House Resolution 441, part 3, pages 1454–1458, 1934.

1934—10,763,000,000 barrels. Petroleum Administrative Board, Report on the Cost of Producing Petroleum, page 133, 1936 (issued December 1935).

1934—12,000,000,000 barrels, probably as of August 1934. Statement of C. B. Ames: Petroleum Investigation; hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, on House Resolution 441, part 1, page 359, 1934.

1934—12,177,000,000 barrels. Estimate by a special committee of the American Petroleum Institute, in Petroleum Production and Supply: American Association Petroleum Geologists Bulletin, volume 20, No. 1, pages 1–14, January 1936.

1934—13,000,000,000 barrels, November 12, 1934. Statement of E. W. Marland: Petroleum Investigation; hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, on House Resolution 441, part 3, pages 1439–1445, 1934.

1934—13,632,000,000 barrels. Estimate by American Petroleum Institute Committee on Petroleum Reserves in Nation's Proven Oil Reserves Placed at 13,000,000,000 Barrels: American Petroleum Institute Quarterly, volume 7, No. 2, page 5, April 1937.

1934—15,000,000,000 barrels. Statement of Campbell Osborn: Petroleum Investigation; hearings before subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-third Congress, on House Resolution 441, part 3, pages 1458–1463, 1934.

1935—10,575,000,000 barrels. V. R. Garfias and R. V. Whetsel, Proven Oil Reserves: American Institute of Mining and Metallurgical Engineers Transactions, volume 118, pages 211–214, 1936.

1935—12,992,000,000 barrels. W. L. Baker, Oil Weekly, volume 80, No. 9, pages 19–22, February 10, 1936.

Estimates of petroleum reserves for years indicated in fig. 6—Continued

Year ending Dec. 31—

1936—12,904,946,000 barrels. L. G. E. Bignell, Oil and Gas Journal, volume 36, No. 37, pages 38–39, January 27, 1938.

1936—13,063,000,000 barrels. Estimate by American Petroleum Institute Committee on Petroleum Reserves, in Nation's Proven Oil Reserves Placed at 13,000,000,000 Barrels: American Petroleum Institute Quarterly, volume 7, No. 2, page 5, April 1937.

1936—15,000,000,000 barrels. J. E. Thomas, Proved Oil Reserves in United States of America: American Association of Petroleum Geologists Bulletin, volume 21, No. 8, pages 1088–1091, 1937.

1936—15,856,190,000 barrels. Institute Committee Estimates, Nation's Proven Petroleum Reserves at New High: American Petroleum Institute Quarterly, volume 8, No. 2, pages 12–13, April 1938.

1937 –12,909,000,000 barrels. Estimate by A. W. McCoy, Oil Weekly, volume 88, No. 8, pages 10–11, January 31, 1938.

1937—13,489,457,000 barrels. L. G. E. Bignell, Oil and Gas Journal, volume 36, No. 37, pages 38–39, January 27, 1938.

1937—13,975,816,944 barrels. L. G. E. Bignell, Oil and Gas Journal, volume 37, No. 35, page 20, January 12, 1939.

1937—15,507,268,000 barrels. Institute Committee Estimates Nation's Proven Petroleum Reserves at New High: American Petroleum Institute Quarterly, volume 8, No. 2, pages 12–13, April 1938.

1937—17,750,839,000 barrels. Estimate by American Petroleum Institute Committee on Petroleum Reserves: American Petroleum Institute Quarterly, volume 9, No. 2, pages 7–8, April 1939.

1938—13,584,000,000 barrels, September 1, 1938. A. W. McCoy, Estimate of Petroleum Reserves, United States, Ponca City, Okla., September 1938.

1938—14,000,000,000 barrels. V. R. Garfias and R. V. Whetsel, Estimate of World Oil Reserves: American Institute of Mining and Metallurgical Engineers Transactions, volume 132, pages 608–611, 1939.

1938—14,351,520,297 barrels. L. G. E. Bignell, Oil and Gas Journal, volume 37, No. 35, pages 20–23, January 12, 1939.

1938—15,890,840,000 barrels. W. L. Baker, Oil Weekly, volume 92, No. 7, pages 44–46, January 30, 1939.

1938—17,348,146,000 barrels. Estimate by American Petroleum Institute Committee on Petroleum Reserves: American Petroleum Institute Quarterly, volume 9, No. 2, pages 7–8, April 1939.

1938—17,505,000,000 barrels. H. C. Wiess, Some Current Problems in Oil Conservation: Oil and Gas Journal, volume 37, No. 41, pages 46–170, February 23, 1939.

1939—18,483,012,000 barrels. American Petroleum Institute Quarterly, volume 10, No. 2, pages 8–9, April 1940.

1939—19,687,379,000 barrels. Oil and Gas Journal, volume 38, No. 37, page 53, January 25, 1940.

1939—18,751,050,000 barrels. Oil Weekly, volume 96, No. 8, page 52, January 29, 1940.

1940—19,024,515,000 barrels. American Petroleum Institute Quarterly, volume 11, No. 2, pages 8–9, April 1941.

1940—20,099,258,000 barrels. Oil and Gas Journal, volume 39, No. 38, page 61, January 30, 1941.

1940—18,735,250,000 barrels. Oil Weekly, volume 100, No. 8, pages 48–49, January 27, 1941.

1941—19,589,296,000 barrels. American Petroleum Institute Quarterly, volume 12, No. 2, pages 1 and 2, April 1942.

1941—20,299,543,000 barrels. Oil and Gas Journal, volume 40, No. 38, pages 60–61, January 29, 1942.

1941—19,524,075,000 barrels. Oil Weekly, volume 104, No. 8, pages 48–49, January 26, 1942.

1942—20,082,793,000 barrels. American Petroleum Institute Quarterly, volume 13, No. 2, pages 3–4, April 1943.

1942—20,675,899,000 barrels. Oil and Gas Journal, volume 41, No. 38, page 65, January 28, 1943.

1942—19,325,899,000 barrels. Oil Weekly, volume 108, No. 9, page 48, February 1, 1943.

1943—20,064,152,000 barrels. American Petroleum Institute Quarterly, volume 14, No. 2, pages 9–12, April 1944.

Estimates of petroleum reserves for years indicated in fig. 6—Continued

Year ending Dec. 31—

1943—20,046,905,000 barrels. Oil and Gas Journal, volume 42, No. 38, pages 116–117, January 27, 1944.

1943—19,755,253,000 barrels. Oil Weekly, volume 112, No. 9, pages 78–83, January 31, 1944.

1944—20,453,231,000 barrels. American Petroleum Institute Quarterly, volume 15, No. 2, pages 35–38, April 1945.

1944—20,514,739,000 barrels. Oil and Gas Journal, volume 43, No. 38, page 184, January 27, 1945.

1944—19,714,723,000 barrels. Oil Weekly, volume 116, No. 9, page 148, January 29, 1945.

1945—20,826,813,000 barrels. American Petroleum Institute Quarterly, volume 16, No. 2, pages 24–26, April 1946.

1945—21,078,024,000 barrels. Oil and Gas Journal, volume 44, No. 38, page 179, January 26, 1946.

1945—20,970,011,000 barrels.. Oil Weekly, volume 120, No. 11, page 113, February 11, 1946.

1946—24,036,779,000 barrels. Reports on Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas, published jointly by American Gas Association and American Petroleum Institute, volume 1.

1946—21,345,138,000 barrels. Oil and Gas Journal, volume 45, No. 38, page 155, January 25, 1947.

1946—21,287,673,000 barrels. Oil Weekly, volume 124, No. 11, page 143, February 10, 1947.

1947—24,741,660,000 barrels. Reports on Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas, published jointly by American Gas Association and American Petroleum Institute, volume 2.

1947—25,984,000,000 barrels. Oil and Gas Journal, volume 46, No. 39, page 170, January 29, 1948.

1947—21,718,302,000 barrels. World Oil Yearbook, volume 127, No. 11, page 178, February 1948.

1948—26,821,227,000 barrels. Reports on Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas, published jointly by American Gas Association and American Petroleum Institute, volume 3.

1948—27,325,000,000 barrels. Oil and Gas Journal, volume 47, No. 39, page 187, January 27, 1949.

1948—22,500,000,000 barrels. World Oil, volume 128, No. 11, page 51, February 15, 1949.

1949—28,378,501,000 barrels. Reports on Proved Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas, published jointly by American Gas Association and American Petroleum Institute, volume 4.

1949—28,586,000,000 barrels. Oil and Gas Journal, volume 48, No. 38, page 191, January 26, 1950.

1949—28,884,955,000 barrels. World Oil, volume 130, No. 3, page 134, February 15, 1950.

HISTORY OF ESTIMATES OF NATURAL GAS RESERVES

Natural gas is a mixture of hydrocarbons and gaseous impurities. It is a companion to crude petroleum and was formed by similar geologic processes. Both petroleum and natural gas are produced from similar and, at many places, common underground reservoirs. The gas and oil are under pressure and occupy pores, cracks, or other openings in the reservoir rocks. Natural gas may occur with, or dissolved in the oil, or it may not be associated with oil. Because oil and gas, like water, are mobile, and have different specific gravities, their process of accumulation in the present reservoirs has involved movement through permeable rock strata to the tops of anticlines or other structures which are sealed by overlying impervious rock strata. In a reservoir where both oil and gas are present, much or all of the gas may be dissolved in the oil, or a gas cap may occur above the oil in the upper part of the reservoir.

Natural gas was first marketed in the United States in 1821 at Fredonia, N. Y., where gas was used in light burners in homes in the village. A growing but modest use of gas as a fuel and illuminant continued in New York, Pennsylvania, Ohio, and West Virginia until 1878, when the first big gas producer in the United States was discovered near Murrysville, Pa. The development of the natural-gas industry expanded greatly, and commercial production and marketing of gas followed shortly in Ohio, West Virginia, Illinois, Indiana, and Kentucky.

The use of natural gas as fuel continued to increase and during the period from 1918, when one of the early estimates of the reserve of natural gas was published, to 1949 the amount of natural gas marketed annually expanded from 721 billion to about 5½ trillion cubic feet. Utilization of natural gas reached an all-time high in 1949. It will probably be even greater in 1950 due to the tremendous extension of natural-gas transmission systems.

An early estimate of total recoverable and marketable reserves in both discovered and undiscovered fields of the United States was made by Eugene W. Shaw, valuation engineer in charge of natural gas, United States Internal Revenue Bureau, and geologist, United States Geological Survey. In a paper presented at the annual meeting of the Natural Gas Association of America, Cleveland, Ohio, May 20–26, 1919, Shaw stated that the total recoverable and marketable reserves in both discovered and undiscovered pools in the United States were probably 5,000 to 15,000 billion cubic feet.

Prior to the beginning of the systematic annual reporting of reserve estimates of natural gas by the American Gas Association in 1946 (for the year ending December 31, 1945) periodic reporting of gas reserves was done by various individuals and by the Petroleum Administration for War during World War II (fig. 9).

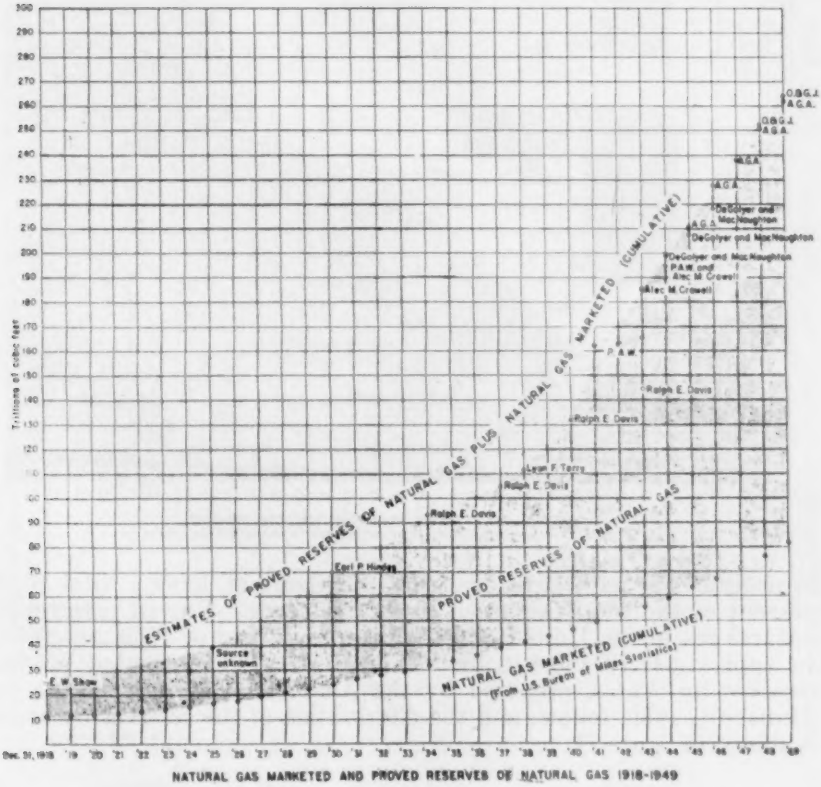
From 1930 to 1938 several estimates were made on different bases. L. G. Huntley and S. L. Mason [24] in 1930 estimated the reserves of gas produced with oil in the United States east of the Rocky Mountains at a minimum of 49.5 trillion cubic feet. The estimate assumed continuance of the past 15-year ratio of discovery of 2,250 cubic feet of gas to the barrel of oil. In October 1931, H. O. Caster,[25] president of the American Gas Association, in discussing developments in the natural-gas industry, estimated that 13 gas fields and gas-producing areas in the United States contained proved reserves of some 30 trillion cubic feet. Garfias [26] estimated the proved reserves of natural gas at the end of 1934 to be 40 trillion cubic feet or, 20 years' supply on the basis of then current consumption. In 1935, Ley [27] estimated the future recoverable gas from proved and important areas to be 75 trillion cubic feet. He stated that most of this reserve had been discovered in the search for oil and that part of the gas would be wasted in producing oil. Davis' [28] estimate of 62 trillion cubic feet as stated in a paper presented before the American Gas Association in May

[24] Huntley, L. G., and Mason, S. L., Gas and Coal Reserves in Relation to Pipe Line and Markets, National Petroleum News, vol. 22, May 14, 1930, No. 20, pp. 34–36.
[25] Caster, H. O., Developments in the Natural Gas Field, Gas Age-Record, vol. 68, October 24, 1931, No. 17, pp. 613–630.
[26] Garfias, V. R., Proven Reserves of Mineral Fuels in the United States, American Institute of Mining and Metallurgical Engineers Transactions, vol. 114, 1935, Petroleum Division, pp. 243–244.
[27] Ley, H. A., Geology of Natural Gas, American Association of Petroleum Geologists, June 1935 (Foreword, p. vii, and Natural Gas, pp. 1073–1149).
[28] Davis, R. E., Conservation of Natural Gas in the United States, Gas Age-Record, vol. 75, June 8, 1935, No. 23, pp. 565–572.

1935 includes only 5.9 trillion cubic feet for California, which differs considerably from the estimate by Hoots and Herold [29] of 34 trillion cubic feet for California. These estimates prior to 1946 were not strictly comparable to one another, as some estimates included gas in solution with crude petroleum and others did not. Also, the estimates were not on a common pressure base, and little is known about the number and minimum size of fields included in their preparation. Systematic estimates of proved reserves of natural gas comparable to the estimates for proved reserves of oil by the American Petroleum Institute were started by the American Gas Association for the year 1945 and have been revised annually to the present time. Although the trend indicated in the discovery of new reserves is only approximate, it is significant that large increases in estimated reserves have been found since 1919 (figs. 9 and 10).

As natural gas is commonly associated with petroleum the areas having the most reserves of liquid hydrocarbons will usually have large reserves of natural gas. Texas, which has 55 percent of the reserves of liquid hydrocarbons, also contains 55 percent of the natural gas reserves of the United States. Louisiana, Kansas, and Oklahoma,

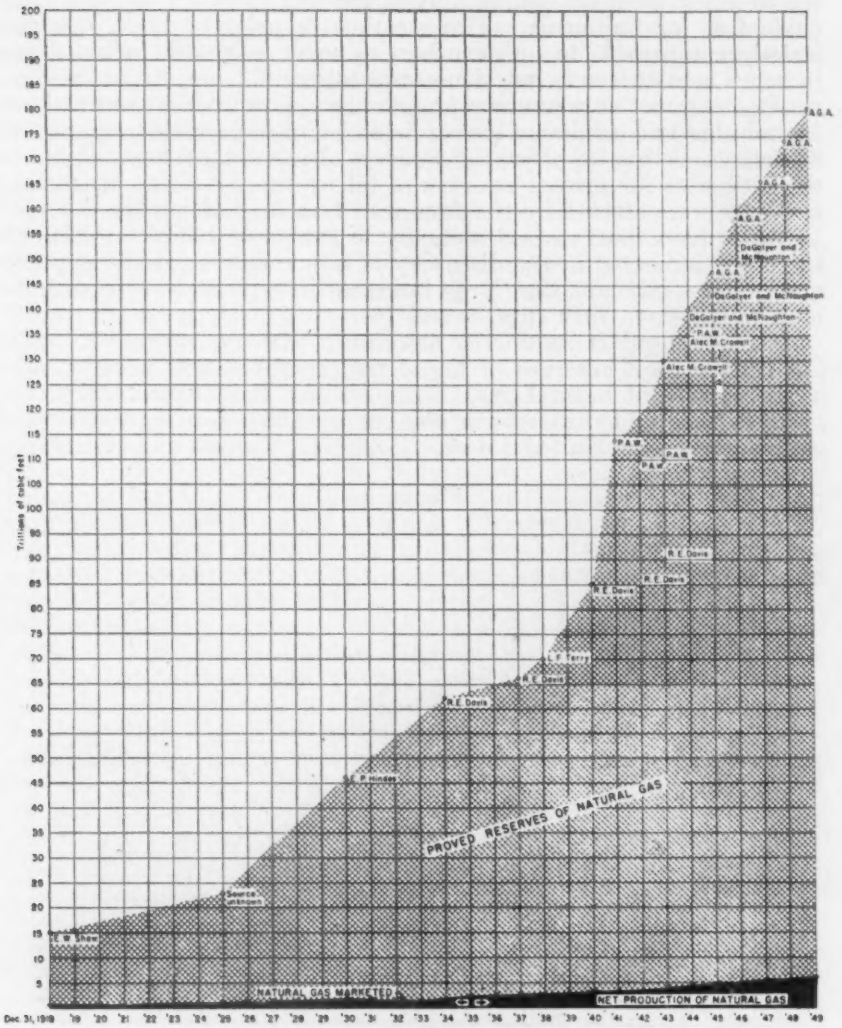
FIGURE 9



NATURAL GAS MARKETED AND PROVED RESERVES OF NATURAL GAS 1918-1949

[29] Hoots, H. W., and Herold, S. C., Natural Gas Resources of California, Geology of Natural Gas, American Association of Petroleum Geologists, June 1935, pp. 113–220.

FIGURE 10


Trillions of cubic feet
PROVED RESERVES OF NATURAL GAS
NATURAL GAS MARKETED
NET PRODUCTION OF NATURAL GAS
Source unknown
A.G.A.
DeGolyer and McNaughton
P.A.W.
Alec M. Crawford
R.E. Davis
L.F. Terry
E.P. Hinds
E.W. Shaw
Dec. 31, 1918
'19 '20 '21 '22 '23 '24 '25 '26 '27 '28 '29 '30 '31 '32 '33 '34 '35 '36 '37 '38 '39 '40 '41 '42 '43 '44 '45 '46 '47 '48 '49

NATURAL GAS RESERVES AND PRODUCTION FROM 1918-1949
Production statistics from U.S. Bureau of Mines. Data on net production available for 1935 and following years.

in order of the natural gas reserves they contain, have a total of 29 percent of the total estimated proved reserves. Proved reserves of natural gas in the United States at the beginning of 1950 amounted to approximately 180.4 trillion cubic feet. The estimated proved reserves by States, prepared by the American Gas Association, on January 1, 1950, follow; and the distribution of the reserves by areas is shown in figure 11.

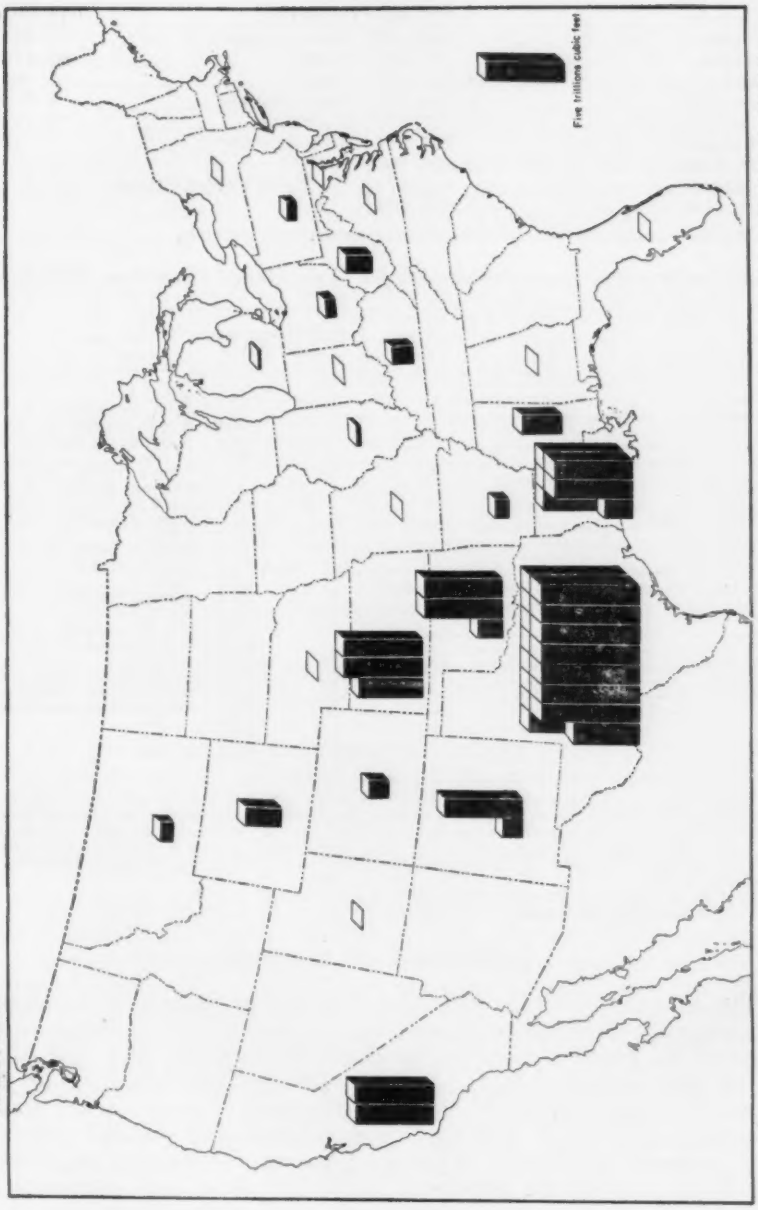

Five trillions cubic feet
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PROVED RESERVES OF NATURAL GAS IN THE UNITED STATES ON JANUARY 1, 1950 AS ESTIMATED BY THE AMERICAN GAS ASSOCIATION

FIGURE 11

Estimated proved reserves of natural gas on Jan. 1, 1950

	Millions of cubic feet		Millions of cubic feet
Arkansas	874, 190	New York	66, 685
California	9, 991, 635	Ohio	652, 571
Colorado	1, 227, 095	Oklahoma	11, 625, 979
Illinois	233, 192	Pennsylvania	621, 680
Indiana	25, 200	Texas	99, 170, 403
Kansas	14, 089, 560	Utah	65, 577
Kentucky	1, 349, 397	West Virginia	1, 715, 233
Louisiana	26, 687, 811	Wyoming	2, 173, 677
Michigan	214, 911	Miscellaneous [1]	23, 105
Mississippi	2, 528, 969		
Montana	803, 471	Total United States	180, 381, 344
New Mexico	6, 241, 003		

[1] Includes Alabama, Florida, Maryland, Missouri, Nebraska, and Virginia.

Estimates of proved reserves of natural gas in the United States from 1918 to 1949[1]

Year [2]	Trillion cubic feet reserves	By—
1918	[3] 15.0	Shaw.
1925	23.0	Source unknown.
1930	46.0	Earl P. Hindes.
1934	62.0	Ralph E. Davis.
1937	66.0	Do.
1938	70.0	Lyon F. Terry.
1940	85.0	Ralph E. Davis.
1941	113.8	PAW.
1942 (Oct. 1, 1942)	85.0	Ralph E. Davis.
1942	110.0	PAW.
1943	90.0	Ralph E. Davis.
1943	100.0–300.0	Lyon F. Terry.
1943	110.0	PAW.
1944	130.0	Alec M. Crowell.
1944	135.0	PAW.
1944	135.0	Alec M. Crowell.
1944	140.0	DeGolyer and MacNaughton.
1945	144.3	Do.
1945	147.8	American Gas Association.
1946	151.0	DeGolyer and MacNaughton.
1946	160.6	American Gas Association.
1947	165.9	Do.
1948	173.9	Do.
1949	180.4	Do.

[1] Mainly from natural gas reserves of the United States as of Jan. 1, 1946, prepared for E. Holley Poe and associates, New York, N. Y., by DeGolyer and MacNaughton, geologists, Dallas, Tex., and presented before the Federal Power Commission by E. DeGolyer on July 17, 1946, in the natural gas investigation (Docket G–580), except the PAW estimate for 1944 which is from papers presented by the Petroleum Administration for War before the Senate Special Committee to Investigate Petroleum Resources, Nov. 28–30, 1945, p. 124.

[2] As of end of year except the estimate by Ralph E. Davis on Oct. 1, 1942.

[3] Total gas in discovered and undiscovered fields.

ESTIMATION OF RESERVES

The estimation of the quantity of liquid or gaseous hydrocarbons in a reservoir that can be classed as a proved reserve involves knowledge of the physical characteristics of the reservoir rock and of the oil or gas contained in it. Among the geologic, engineering, and economic factors involved in the estimation of reserves are size of reservoir; thickness, porosity, and permeability of the reservoir rock; presence or absence of gas with the oil; existence of an effective water drive; reservoir pressure; production rate; and economic life of the field. During the development of a field the knowledge of the conditions controlling the occurrence of the oil or gas is limited and reserves generally may be estimated with reasonable accuracy only as development approaches completion. Preliminary estimates of

the reserves of oil or gas in a field made during its development must be based upon few data, inferences regarding subsurface conditions, and comparisons with other fields producing from similar reservoirs. Such preliminary estimates may be close approximations to the final estimates or may be subject to considerable modification.

Estimates of the proved reserves of oil or gas for the entire country must include fields in all stages of development ranging from newly discovered fields to fields approaching the end of their productive lives. The American Petroleum Institute has adopted the practice of including in their estimate of oil reserves the quantity of oil that may be considered to be proved by current development and of revising their estimates in subsequent years as development progresses. Their practice is described in the following quotation from the report of proved reserves at the end of 1949:

> In the case of new discoveries, both of new fields and of new pools (pays, reservoirs) in oil fields, which are seldom fully developed in the first year and in fact for several years thereafter, the estimates of proved reserves necessarily represent but a part of the reserves which may ultimately be assigned to the new reservoirs discovered each year. For a one-well field, where development has not yet gone beyond the discovery well, the area assigned as proved is usually small in regions of complex geological conditions but may be larger where the geology is relatively simple. In a sparsely drilled pool the area between wells is considered to be proved only if the geological and engineering data assure that such area will produce when drilled. The total of new oil through discoveries estimated as proved in any given year is generally comparatively small, because development is usually not extensive during the first year. The total of new oil through extensions, on the other hand, is comparatively large. As knowledge of the factors affecting production and reservoir performance becomes available, and as these factors are studied, reserves in older fields can be estimated with greater precision and revised accordingly. Therefore, the total quantity of the new proved reserves for the year includes the oil from discoveries, extensions, and revisions of previous estimates.

Similarly the committee on natural gas reserves of the American Gas Association includes the following statement in its report for 1949:

> The committee wishes to point out again that it is often not possible to estimate the total reserves of a field in the year of its discovery. Satisfactory estimates can be made only after there has been sufficient drilling in the field and, in some cases, adequate production history. For these reasons, the reserves listed as discovered during any current year must be considered only as the reserves indicated by the drilling in that year. The estimated reserves of the new fields and pools will be revised in future reports and shown as "Extensions and revisions."

Our knowledge of proved reserves of oil and gas is provided by the industry which is drilling at the current rate of about 43,000 exploratory and development wells a year. An increasing amount of data is obtained annually by which a more accurate estimation of the total proved reserves can be made. It is only through drilling, coring and testing that these data become available, without which, estimates of reserves are only guesses.

The industry obtains the basic data used in preparing estimates of reserves in its normal exploratory and development program. For their own efficient operation and to maintain their positions in a highly competitive field, companies must assemble data on the availability of their reserves. The aggregate of these individual estimates by innumerable individuals on the technical staffs of the companies is believed to be the most accurate and comprehensive estimate that can be assembled. The scope and diversity of participation in the

committees that make and review the reserve estimates should assure unbiased estimates.

POTENTIAL RESERVES

The following discussion reviews briefly the history of estimates of possible oil reserves. Many criteria have been used in these evaluations, such as volume of sediments; whether marine or nonmarine; character of sediments, that is, whether sandstone, shale, limestone, or other types; amount of organic matter contained in sediments; and projection into the future of past trends of production from various types of rocks of various ages. Undoubtedly as geologic knowledge of oil-bearing rocks becomes more complete and production research develops, each estimate based on exhaustive research will be more accurate, but the time has not yet arrived when a definitely accurate estimate of ultimate potential production can be made.

In 1921 the United States Geological Survey, in cooperation with the American Association of Petroleum Geologists, prepared an estimate of oil "in sight" amounting to 5 billion barrels and "prospective and possible" oil amounting to 4 billion barrels as of January 1, 1922.[30] The committee making the estimates emphasized that the estimates of oil in "possible" territory were speculative and hazardous as the questions involved in a particularly doubtful region are not only how much oil it will yield but also if it will yield any oil. The estimates were considered to be distinctly conservative by the committee, and subsequent discoveries have made it abundantly clear that the estimates were ultraconservative.

These estimated reserves were considered to be sufficient for the current requirements of the United States for only 20 years, if the oil could be produced as fast as it was needed. However, the committee pointed out that, although there was enough oil for 20 years at the rate of consumption at that time, all the oil pools would not be found within that length of time, that drilling would be spread over many years as the pools were found, and the wells could not be quickly exhausted. Some wells would yield oil for more than 25 years, and some would not have been drilled by 1950.

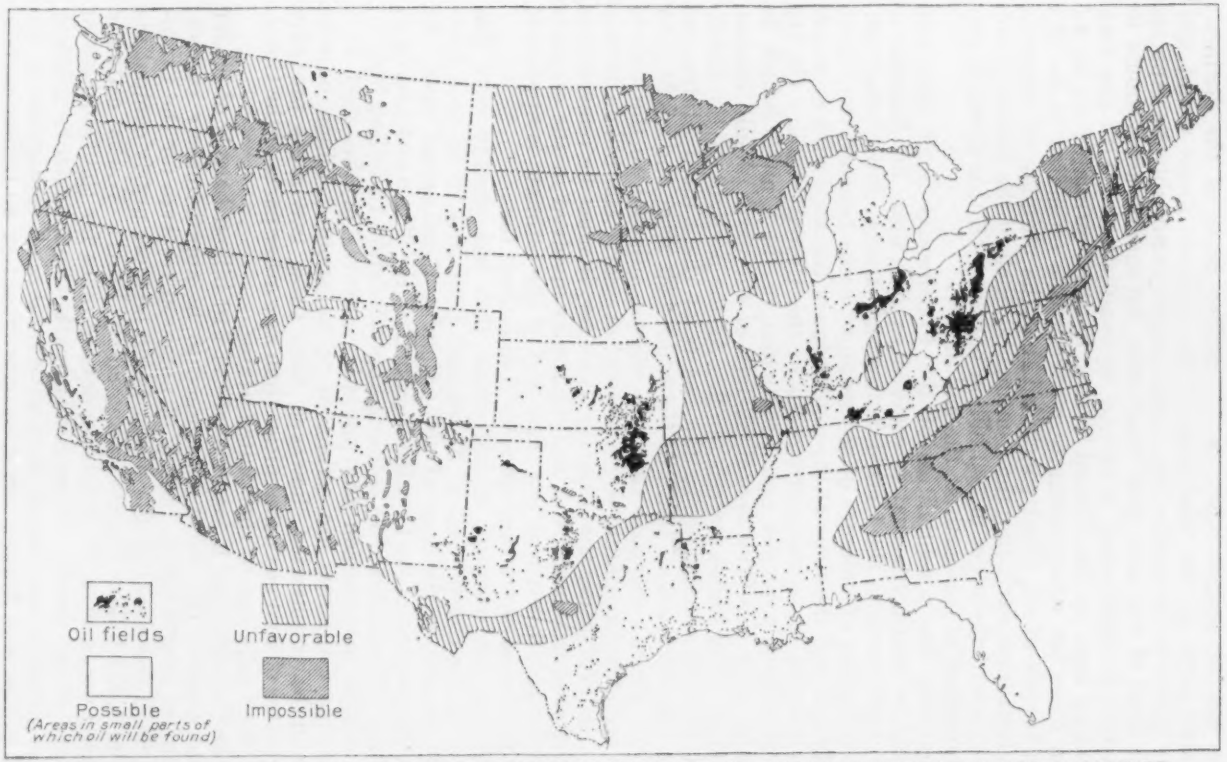
The annual estimate of proved petroleum reserves prepared by the American Petroleum Institute since 1936 does not include any estimate of crude oil under the unproved portions of partly developed fields, crude oil in untested prospects, crude oil that may be present in regions believed to be generally favorable, crude oil that may become available by secondary recovery methods from fields where such methods have not been applied, crude oil that may become available through chemical processing of natural gas, and liquid hydrocarbons that can be produced from oil shale, coal, or other bituminous matter.

Unknown quantities of oil and gas remain to be discovered in new fields and deeper productive zones in the areas indicated as "possible" on the accompanying map (fig. 12). In attempting to estimate the ultimate petroleum resources of the United States, Pratt[31] stated that probably the best guide is a projection into the future of the trends established by our past experience in the search for oil and gas. Of the total area in the United States definitely tested by

[30] American Association of Petroleum Geologists (1922), The Oil Supply of the United States, American Association of Petroleum Geologists Bulletin, vol. 6, no. 1, pp. 42–46.

[31] Pratt, Wallace E. (1950) The Earth's Petroleum Resources, pt. 1, ch. VI, Our Oil Resources, edited by L. M. Fanning, pp. 150–151.

FIGURE 12



MAP OF THE UNITED STATES SHOWING DISTRIBUTION OF OIL FIELDS AND UNPRODUCTIVE AREAS CLASSIFIED WITH RESPECT TO THEIR RELATIVE LIKELIHOOD OF YIELDING COMMERCIAL QUANTITIES OF OIL

drilling, 1 to 2 percent proved to be productive; in favorable sedimentary basins the average commercially productive area has been more than double this average. Pratt concluded that if 1.5 percent of the 900,000 square miles, or 577 million acres of the distinctly favorable parts of the land area of the United States would ultimately prove to be productive, which might reasonably be expected on the basis of our total past experience, 8.6 million acres should be productive if exploration is carried to completion. With the total productive area in the United States in 1948 estimated to be 4.5 million acres for which ultimate recovery was estimated to be 57.2 billion barrels of oil, Pratt concluded that the ultimate oil resources of the land area, excluding the Continental Shelf of the United States (fig. 13) are of the order of 100 billion barrels. Of this total, 65 percent remained in the earth at the end of 1947.

Regarding the potentialities of the Continental Shelf (the area adjacent to continents that is covered by less than 100 fathoms of water) contiguous to the United States and Alaska, Pratt[32] has compared estimates of volumes of sedimentary rocks beneath the Continental Shelf and the slope at the outer edge of the shelf with estimates of the volume of sedimentary rocks in the United States. On the basis of past discoveries and production in the United States he concludes that the Continental Shelves of the earth should contain more than 1,000 billion barrels of oil. As the portions of the Continental Shelves contiguous to the coasts of the United States and Alaska include nearly a tenth of the total shelf area, one might infer from Mr. Pratt's estimate that the shelves adjacent to the United States and Alaska contain a grand total of nearly 100 billion barrels of oil. In evaluating the estimate, however, it must be remembered that the seaward margins of the sediments involved in the estimate extend far out to sea and less than half of the estimate is applicable to the shelf area shoreward from the 100-fathom line.

Based on the quantity of petroleum that has already been discovered in the coastal belt of Texas and Louisiana in an area comparable in size to the area of the adjoining Continental Shelf, the petroleum reserves of the Continental Shelf off the Texas and Louisiana coasts may be estimated as totaling approximately 13 billion barrels. By a similar comparison the potential reserves of the shelf area adjacent to California are estimated to be about 2 billion barrels. It should be emphasized, however, that these two areas probably have greater oil and gas possibilities than any other parts of the Continental Shelf adjacent to the United States.

Weeks[33] states that if his estimate of 610 billion barrels of oil for the land areas of the world is assumed to be approximately correct, an estimate of 400 billion barrels of potential reserves for the Continental Shelf sediments of the world would be more nearly compatible than the 1,000 billion barrels estimated by Pratt. Weeks' estimate was based on an area of 10 million square miles for the Continental Shelf area of the world. From his estimate it could then be inferred that the potential reserves of the Continental Shelf contiguous to the United States and Alaska would be approximately 40 billion barrels. With an area of about 290,000 square miles for the Continental Shelf

[32] Pratt, Wallace E. (1947), Petroleum on Continental Shelves, American Association Petroleum Geologists Bulletin, vol. 31, No. 4, pp. 657–672.
[33] Weeks, L. G. (1950), Concerning Estimates of Potential Oil Reserves, American Association Petroleum Geologists Bulletin, vol. 34, No. 10, pp. 1947–1953.

UNITED STATES DEPARTMENT OF THE INTERIOR
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Figure 13

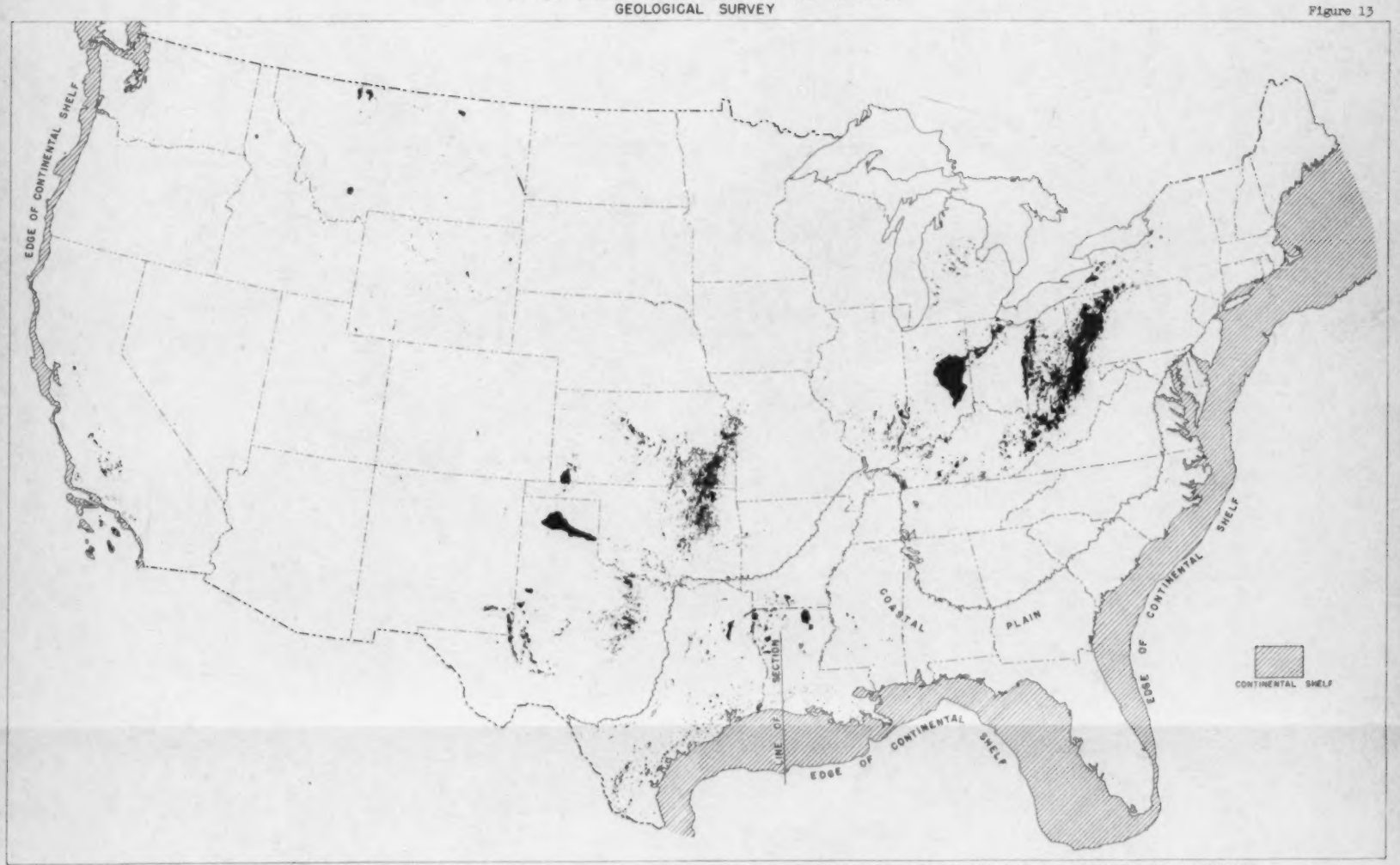
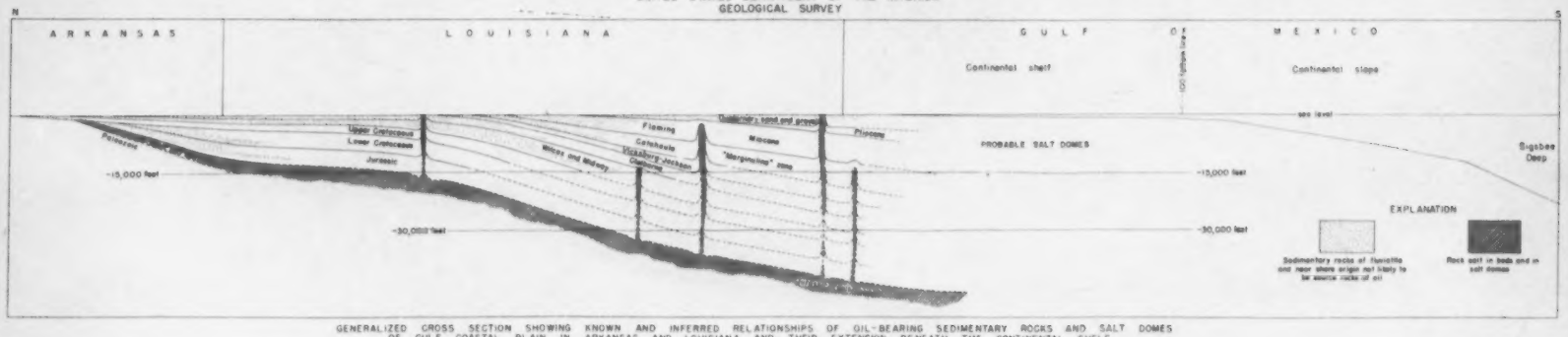


FIGURE 13 MAP OF THE OIL AND GAS FIELDS OF THE UNITED STATES, SHOWING GULF AND ATLANTIC COASTAL PLAIN AND THE CONTINENTAL SHELVES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



GENERALIZED CROSS SECTION SHOWING KNOWN AND INFERRED RELATIONSHIPS OF OIL-BEARING SEDIMENTARY ROCKS AND SALT DOMES OF GULF COASTAL PLAIN IN ARKANSAS AND LOUISIANA AND THEIR EXTENSION BENEATH THE CONTINENTAL SHELF

10 0 10 20 30 40 Miles

80424 O - 51 (Face p. 32)

area adjacent to the United States, it can be inferred from Weeks' conclusions that the estimated potential reserves adjacent to the Continental United States would be approximately 11.6 billion barrels; the Continental Shelf area adjacent to Alaska is about 590,000 square miles, and the reserve estimate would be 23.6 billion barrels.

Oil in sedimentary rocks cannot be considered to constitute reserves unless it can be economically exploited. Hence, as the cost of producing oil on the Continental Shelf will be considerably greater than on land the economic limit of production in the fields on the Continental Shelf would be reached earlier in the life of these fields and the ultimate recovery would be less.

Based upon the record of discovery in the past and careful analyses of geologic data, Weeks [34] estimated the ultimate potential petroleum resources of the United States as 110 billion barrels, with a total of about 53.4 billion barrels yet to be discovered. Previously, in 1946, Joseph E. Pogue [35] estimated the oil remaining to be discovered in the United States amounted to 50 billion barrels.

An important factor in attempts to evaluate potential reserves is the increment of oil left in the ground when oil fields are depleted by current production methods. The average recovery from producing fields is far from complete. An accurate figure is not available, but may be assumed to be of the order of magnitude of 50 percent. Thus the existence, location, and conditions of occurrence of vast quantities of oil that is not recoverable at present are known. The development or application of techniques for recovery of increasingly large amounts of this oil may be anticipated. Any additional discoveries or increases in recovery of oil in basins of sedimentary rocks affects the basis of estimating in methods based upon past discoveries from such rocks with consequent increase in estimates of the quantity of oil remaining to be discovered.

Present status of basic data.—Regional geologic information provides the foundation essential to the intelligent search for petroleum and natural gas. A relatively small part of the Continental United States has been mapped or studied geologically in sufficient detail to provide the data necessary for guiding exploration and interpreting results of drilling.

During 1950, 43,279 wells were drilled and 8,554 wildcat tests were completed; total footage drilled was 159,287,865 feet or an increase of 21,285,000 feet over the year 1949; the average depth of wells likewise increased during the year by 142 feet to 3,680 feet.[36] More of the stratigraphic section is being explored and drilling and production have been extended into new areas.

On the basis of past results, there is no question but that increasingly critical and more detailed studies of the stratigraphy and paleontology of potentially oil- and gas-bearing rocks will lead to many new discoveries. Because most of the easily-found traps, particularly those on folded structures, have already been exploited, and new discoveries are becoming more and more the result of intelligent research and application of modern technology, it is believed that the most effective research will be in the fields of stratigraphy, with emphasis on stratigraphic paleontology, sedimentation, and geologic history.

[34] Weeks, L. G. (1948), Highlights on 1947 Developments in Foreign Petroleum Fields, American Association Petroleum Geologists Bulletin, vol. 32, No. 6, pp. 1093–1160.
[35] Pogue, Joseph E. (1946), Oil in the World, Yale Review, N. S. 35, pp. 623–632.
[36] Oil and Gas Journal, vol. 49, No. 38, January 25, 1951, pp. 184–185.

Only the broader aspects of the stratigraphy and structure of the Continental Shelf areas adjacent to the United States and Alaska are known. Pratt [37] states that the sediments of the continental shelves of the world are better adapted to contain great quantities of petroleum than the marine strata deposited from time to time in the past on what is now land area. He concludes that the volume of the sediments on the continental shelves of the world, favorable for petroleum resources, is greater than the aggregate volume of the marine sediments of this character beneath the present land surfaces, and is on the order of 50 to 60 million cubic miles as compared with 20 million cubic miles of marine strata within the present land areas in the world. Within the boundaries of the United States, he estimates the volume of marine sediments of favorable character as about 3 million cubic miles and in these sediments about 57 billion barrels of oil have been discovered. If the sediments of the continental shelf areas of the world are an equally favorable environment for petroleum resources as the sediments of favorable character within the land area of the United States and are 20 times larger in volume, they must contain a great store of oil.

In 1944 L. F. Terry [38] estimated future production of natural gas amounting to 300 trillion cubic feet or more at a time when the highest estimate of proved gas reserves was 110 trillion cubic feet and the annual production was about 4 trillion cubic feet. Since then new fields have been discovered, old fields have been enlarged, and the annual rate of production has increased to 6.25 trillion cubic feet for 1949. In a recent article [39] Terry stated that in the light of new evidence his 1944 estimate of future supply appears to have been entirely too conservative and from the present evidence he considers the future recoverable natural gas in this country will exceed 500 trillion cubic feet.

A continuation of coordinated field and laboratory studies of the stratigraphy and paleontology of potential oil- and gas-bearing strata in lesser-known areas, such as is now being carried on by the Geological Survey, has paid dividends in the past and should continue to aid in the search for oil and gas in the future. These studies provide basic data essential to the proper development and administration of public lands, and to the interpretation of types of geologic traps in which oil and gas accumulate, the history of conditions responsible for them, and the reasons for the amount and types of oil and gas accumulated in them. In addition, adequate stratigraphic and paleontologic knowledge is of value in avoiding wasteful and costly drilling, in formulating development programs, and in insuring that a minimum of potential producing zones and fields will be overlooked or inadequately tested.

Such a research program, to which industry voluntarily contributes much basic geologic data, should continue to expand along already established lines. The Government can advantageously develop the broad geologic background which will stimulate new and more effective development and research programs by both companies and individuals.

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[37] Pratt, Wallace E. (1950) The Earth's Petroleum Resources, pt. 1, ch. VI, Our Oil Resources, McGraw-Hill Book Co.

[38] Terry, Lyon F., Our Natural Gas Reserves Will Exceed 500 Trillion Cubic Feet, Proc., Natural Gas Department, American Gas Association, 1944, pp. 133–137.

[39] Terry, Lyon F., The Future Supply of Natural Gas, Gas Age, vol. 106, No. 9, 1950, pp. 58–60, 98, 100, 102.

No precise statement as to the amount of potential reserves of oil and gas in the United States can yet be made. If the future can be judged by the past, oil and gas will be found in sufficient quantities for many years to come. In the United States adequate production has been a direct function of economic incentive. Until the unpredictable date at which that incentive fails to provide the needed supplies, there will be no convincing evidence that we have reached the limits of our ability to expand the potential ultimately recoverable reserves of petroleum.

Oil Shale Reserves

The term "oil shale" is applied to several varieties of fine-textured sedimentary rocks that contain solid organic matter, part of which can be converted to oil and combustible gas by destructive distillation. The contained solid organic matter is mostly unaffected by ordinary solvents but is capable of yielding oil when heated in a retort; only shale yielding more than 10 or 15 gallons of oil per ton is commonly classed as oil shale.

Two types of oil-shale deposits in the United States have been considered in the past as large potential sources of synthetic oil. They are the rich Tertiary oil shales in the Rocky Mountain region and the lower-grade black shales mostly of Paleozoic age in the Eastern States (see map) and a few Western States. Small deposits of cannel shale, that are essentially cannel coal, in the Pennsylvanian coal-bearing rocks in the Eastern States have also been considered as a possible source of oil.

TERTIARY OIL SHALE

The largest high-grade oil-shale deposits known in the United States are in the Green River formation of early Tertiary age in Colorado, Utah, and Wyoming. Smaller high-grade deposits of younger Tertiary age are known in Nevada. Winchester [40] in 1928 estimated that the Tertiary oil shale in these States contained about 125 billion barrels of oil of which about 75 billion barrels would be recoverable. His estimate of the shale oil contained in the Tertiary oil shales was based on reconnaissance mapping, detailed examination of the oil-shale sequence in widely separated surface sections, and a limited amount of sample data, mostly from outcrops. In preparing his estimate he assumed that mining of beds as little as 1 foot thick would be feasible. No shale yielding less than 15 gallons of oil per ton and no oil shale yielding less than 3,000 barrels of oil per acre was considered minable. He used minimum thickness of 1 foot for beds yielding 60 gallons of oil per ton and 4 feet for beds yielding 15 gallons of oil per ton.

Since the above estimates were made, the United States Bureau of Mines and other engineering groups have contemplated large-scale underground mining of the richer and thicker oil-shale zones yielding 25 to 30 gallons or more oil per ton and the Bureau of Mines has operated an experimental plant for treatment of the oil shale near Rifle, Colo.; some consideration has been given to the mining of

[40] Winchester, D. E., The oil possibilities of the oil shales of the United States; Report II of the Federal Oil Conservation Board, appendix 1, January 1928.

thinner oil-shale zones containing a barrel or more of oil per ton of shale and also to the extraction of oil from thick shale zones yielding as little as 15 gallons of oil per ton. A large amount of new sample data has been obtained in connection with these investigations for one of the more favorable oil-shale areas near Rifle in western Colorado, and scattered samples have been obtained from other parts of the Green River oil-shale deposits in Colorado, Utah, and Wyoming. The more recent sample data, mostly from drilling, show generally a greater amount of oil shale and higher oil yields than were known to Winchester.

Revised estimates based on detailed mapping and abundant samples have been made for part of the Green River oil shales in western Colorado in an area of about 260 square miles that includes perhaps the richest readily accessible part of the oil shale in the Piceance Creek Basin. This area may serve as an example of the oil-shale resources of the region. It is located near Rifle and DeBeque. The oil shale contains a rich zone known as the Mahogany ledge that ranges from about 15 feet to 135 feet in thickness and has an average yield of 25 to 30 gallons of oil per ton of shale. The Mahogany ledge in this area is estimated to contain about 30 billion barrels of oil or possibly 18 billion barrels of recoverable oil.[41] The richest part of the zone with an average yield of 45 gallons per ton, and ranging from 5 to 30 feet thick has an oil content of about 6 billion barrels, or about 3.6 billion barrels of recoverable oil. The complete section of oil shale in this area that contains an average of about 15 gallons of oil per ton, including the richer oil shales of the Mahogany ledge, is estimated to contain about 130 billion barrels of oil, disregarding mining and retorting losses.

Although sample data is less abundant for remaining parts of the Green River formation in Colorado, several sample sections are available. From part of these data Belser[42] estimated that rich oil shale of the Mahogany ledge yielding 25 to 30 gallons of oil per ton underlies approximately 1,000 square miles in the Piceance Creek Basin of western Colorado and contains about 100 billion barrels of oil. He also estimated that oil shale of the same area containing an average of 15 gallons of oil or more per ton, and including the rich shale of the Mahogany ledge, has a total content of 300 billion barrels of oil.

Since these estimates were made, new sample data from drilling in the central part of the Piceance Creek Basin indicate that the lower-grade reserve of the basin is much larger. The central part of the basin contains an oil-shale sequence about 2,000 feet thick containing an average of about 20 gallons of oil per ton or approximately 1.9 billion barrels per square mile. Total oil in the shale of the area is estimated to be about three-quarter trillion barrels from shale averaging 15 gallons or more per ton. Much of this reserve is under approximately 1,000 feet of overburden and is remote from outcrop. Accurate data showing detail of distribution of the deposits must await further drilling.

Only a small part of the oil-shale deposits of western Colorado has been carefully sampled and mapped in detail. The major part of

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[41] Duncan, D. C., and Denson, N. M., Geology and Oil Shale Deposits of Naval Oil Shale Reserves 1 and 3, Garfield County, Colo.: U. S. Geological Survey, Oil and Gas Investigations, preliminary map 94, 1949.
Waldron, F. R., Donnell, J. R., Wright, Fred, Geology of the DeBeque Oil-Shale area, Garfield and Mesa Counties, Colo.: U. S. Geological Survey report in preparation.

[42] Belser, Carl, Oil Shale Resources of Colorado, Utah, and Wyoming, American Institute of Mining and Metallurgical Engineers Technical publication No. 2358, 1948.

the Tertiary oil-shale deposits in Colorado, Utah, and Wyoming is known only from reconnaissance mapping and a small amount of sample data. Of approximately 6,315 square miles of area in these States that is classified as land valuable for oil shale, accurate data as to thickness, distribution, and oil yield of the shale is available for only a few hundred square miles.

BLACK SHALE

Black-shale deposits, mostly of Paleozoic age, are widespread throughout several Eastern States, namely Indiana, Ohio, Kentucky, Tennessee, Missouri, Illinois, Michigan, New York, and Pennsylvania, and in some Western States, including Montana, Wyoming, Idaho, Utah, and Nevada. Though samples of some thin beds in such deposits have yielded as much as 25 gallons of oil per ton, units of minable thickness generally yield less than 15 gallons of oil per ton according to the relatively small amount of available sample data and no zones as much as 15 feet thick assaying as much as 15 gallons of oil per ton have been recorded. Because of their lower oil yield the black shales are generally of less interest as a source of liquid fuel than the Tertiary oil shales of the Rocky Mountain region.

As a large part of the Devonian black shales of the Eastern States are close to the surface it is possible to mine them by open-cut methods. Winchester [43] considered that these shales could be mined more cheaply and the oil would be closer to market than the oil shales of the Western States. He used the following limiting factors in preparing his estimates:

1. No shale less than 1 foot thick is considered minable.
2. No shale which will yield less than 10 gallons of oil per ton of shale is considered minable.
3. No shale which will yield less than 2,000 barrels of oil per acre is considered minable.
4. Only oil shale which can be mined by open-cut or steam-shovel methods is considered in making the estimates, and it is estimated that 90 percent of the shale in the ground would reach the retorts for treatment.

Winchester's estimate of oil recoverable from Devonian black shales:

State	Average oil yield, gallons per ton	Total oil barrels	Recoverable oil barrels
Indiana	Greater than 10	7,680,000,000	6,912,000,000
Kentucky	do	10,978,560,000	9,880,704,000
Total [1]		18,658,560,000	16,792,704,000

[1] No estimate is made for Ohio and Tennessee although it is recognized that there are doubtless areas of minable shale in these States.

Since Winchester's estimates of these deposits were made a small amount of new sample data have become available, but these are insufficient to modify his estimates. The Devonian black shales, however, underlie extensive areas where little data is available as to their oil yield.

[43] Winchester, D. E., idem.

SUMMARY

Although data are incomplete for an accurate estimate of the total reserve of shale oil available in the United States, it appears likely that deposits yielding from 10 to 50 or more gallons of oil per ton contain a total of 1 trillion or more barrels of oil, of which perhaps 500 billion barrels could be recovered. Higher-grade parts of the Tertiary oil shales, yielding 25 gallons or more per ton that are of principal interest at the present time, are estimated to contain more than 100 billion barrels of oil of which about one-half might be recoverable.

Bituminous Rock and Related Asphaltic Deposits

Rocks containing bituminous material that can be extracted by organic solvents, low-temperature thermal treatment, or combined mechanical-chemical-thermal processes are widely distributed in the United States, mostly in the petroleum producing regions. These deposits of asphaltic sandstone, bituminous limestone, and bituminous siltstone constitute a large potential source of liquid fuel although most of the interest in them in the past has been for suitable materials for road surfacing or other construction purposes. Vein deposits of gilsonite, grahamite, and other solid hydrocarbons mined for industrial uses are not sufficiently abundant to be considered a major potential source of fuels.

Production of asphalt in the United States was mainly from natural asphalt or bituminous rock deposits until about 1907, when refinery residues from petroleum became the chief source. Total production of natural asphalt and bituminous rock in the United States has been of the order of magnitude of 20 million tons containing possibly 1.5 million tons of bitumen or asphalt and the total production of gilsonite has been about 1.6 million tons. The production of bituminous rock in the United States in 1949 was about 1.1 million tons with an estimated bitumen content of 6 to 10 percent whereas the production of asphalt from petroleum residues was about 9 million tons.

Although rocks containing bituminous material are widely distributed in the United States, known deposits that are sufficiently rich in bitumen to yield 20 to 40 gallons of oil per ton of rock and are accessible for large-scale low-cost mining are relatively few in number. The quantity of oil available from all of these deposits has not been estimated but probably would amount to a few billion barrels that could be recovered at a cost somewhat greater than the present cost of similar petroleum products.

Available data on asphalt and related bituminous rock deposits of the United States, were summarized by Eldridge (1901),[44] and more recently by Abraham (1945).[45] Detailed studies to determine reserves of some of the more promising bituminous rock deposits in the western United States have been made by the Geological Survey, and include studies of deposits near Vernal and Sunnyside, Utah; near the towns of Edna, Santa Cruz, Casmalia, and McKittrick in California; and near Uvalde, Tex. A few promising deposits in California have been examined in recent years by private industry as a possible source of fuel. Other extensive deposits in Oklahoma, Alabama, and Kentucky have been used for construction materials.

[44] Eldridge, G. H., The Asphalt and Bituminous Rock Deposits of the United States, U. S. Geological Survey, Twenty-second Annual Report, pp. 211–453, 1901.
[45] Abraham, Herbert, Asphalts and Allied Substances, fifth edition, vol. 1, 1945.

Reserves of bitumen in the more promising deposits of bituminous rock in the western United States for which reserve data are available are listed in the accompanying table. Data available on bituminous rock deposits in Kentucky, Alabama, Oklahoma, and Missouri are too meager to be a basis for estimates of available liquid fuel.

Reserves of oil from several bituminous rock deposits amenable to large-scale mining in western United States

Area	Reserves of bituminous rock	Average oil yield	Total oil in the deposit	Recoverable oil assuming 50 percent of total oil reaches processing plant
	Short tons	*Gallons per ton*	*Barrels (42 gallons)*	*Barrels of oil*
1. Vernal, Utah[1]	1,764,000,000	31.0	1,207,000,000	603,500,000
2. Sunnyside, Utah[2]	1,416,000,000	21.6	728,000,000	364,000,000
3. Edna, Calif[3]	283,000,000	26.0	175,000,000	87,500,000
4. Santa Cruz, Calif[4]	17,000,000	24.0	10,000,000	5,000,000
5. McKittrick, Calif[5]	10,000,000	21.0	5,000,000	2,500,000
6. Uvalde, Tex[6]	340,000,000	19.0	154,000,000	77,000,000
7. Other large deposits in California		20.0–30.0	250,000,000	125,000,000
Total			2,529,000,000	1,264,500,000

[1] Spieker, E. M., Bituminous Sandstone Near Vernal, Utah: U. S. Geological Survey Bulletin 822c, pp. 77–100, 1931. The reserve estimate is based on the most promising 2 of the 3 tracts in the district and includes bituminous sandstone within 1½ miles of the outcrop.

[2] Holmes, C. N.; Page, B. M.; and Averitt, Paul, Geology of the Bituminous Sandstone Deposits Near Sunnyside, Carbon County, Utah: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 86, 1948. The figures include the measured, indicated, and inferred reserves of bituminous sandstone within 1 mile of the outcrop which are assumed to contain at least 9 percent bitumen.

[3] Page, B. M.; Williams, M. D.; Henrickson, E. L.; and others, Geology of the Bituminous Sandstone Deposits near Edna, San Luis Obispo County, Calif.: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 16, 1944. The figures include measured, indicated, and inferred reserves of bituminous sandstone which has no more than 50 feet of overburden and which is moderately to highly bituminous in existing exposures.

[4] Page, B. M.; Williams, M. D.; Henrickson, E. L.; and others, Geology of the Bituminous Sandstone Deposits near Santa Cruz, Santa Cruz County, Calif.: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 27, 1945. The figures represent the measured, indicated, and inferred reserves of 2 mapped areas of bituminous sandstone and the inferred reserves of the intervening and outlying deposits.

[5] Page, B. M., et al., Asphalt and Bituminous Sandstone Deposits of Part of the McKittrick District, Kern County, Calif.: U. S. Geological Survey Oil and Gas Investigations Preliminary Map 35, 1945. Figures include indicated and part of inferred reserves with no more than 100 feet of overburden.

[6] Gorman, J. M., and Robeck, R. C., Asphalt Deposits Near Uvalde, Uvalde County, Tex.: U. S. Geological Survey report in open file for Texas, 1946. The figures include the measured, indicated, and inferred reserves of bituminous limestone.

Comparison Between Reserves of Various Fuels

As has been summarized in the preceding parts of this statement, the present state of knowledge is such that the quantitative estimation of our mineral fuels reserves is beset by many hazards to accuracy. Because of the differences in nature of occurrence of these fuels and consequent differences in the methods used to appraise their reserves, no simple comparisons adequately express the relationships between them. The accompanying table (table 3) attempts, however, to summarize the mineral fuel reserves of the United States as of January 1, 1950, that may be fairly considered as assuredly recoverable. For petroleum and natural gas, the figures are those of the American Petroleum Institute and the American Gas Association.

The figures for recoverable reserves of petroleum and natural gas are impressive and have a firm foundation on a substantial accumulation of reliable data. Because of the methods which must be used in their calculation, however, these figures are not directly comparable with the estimates of reserves made for coal or for oil shale. Nor are the figures for successive years strictly comparable with each other.

Each as compiled includes currently proved oil and gas reserves recoverable by present methods but do not include the oil or gas in expected extensions to some known fields and obviously cannot include the new discoveries that may with confidence be expected in the years to come. Inasmuch as efficiency of recovery has progressively and substantially improved, each increase in the figures includes not only new oil or gas discovered but an increment of newly recoverable oil from discoveries dating back through the years. The figures in table 3 for petroleum and natural gas must be considered as minimum figures and therefore less than the amount of these substances that is almost certain to be recoverable.

TABLE 3.—*Total assured recoverable mineral fuel reserves of the United States, Jan. 1, 1950*

Type of mineral fuel	Assured recoverable reserves and average annual production (coal in billions of short tons; petroleum, bitumen from bituminous sandstone, and oil from oil shale in billions of barrels; and natural gas in trillions of cubic feet)		Assured recoverable reserves and average annual production (in quadrillions of B. t. u.) [1]		Ratio of assured recoverable reserves, as currently appraised to average annual production, 1940–50	Percent of total assured recoverable mineral fuel reserves on B. t. u. basis, Jan. 1, 1950
	Assured recoverable reserves, Jan. 1, 1950	Average annual production, 1940–50	Assured recoverable reserves, Jan. 1, 1950	Average annual production, 1940–50		
Coal:						
Bituminous coal	[2] 184.90	0.544	4,807.40	14.14	----------	52.38
Subbituminous coal	[2] 70.16	.007	1,333.04	.13	----------	14.53
Lignite	[2] 106.72	.003	1,430.05	.04	----------	15.58
Anthracite and semianthracite	[2] 2.07	.057	52.58	1.45	----------	.57
Total coal, all ranks	363.85	.611	7,623.07	15.76	484	83.06
Petroleum	[3] [4] 28.38	1.780	170.28	10.68	16	1.86
Bitumen from bituminous sandstone	[5] .65	([6])	3.90	([6])	----------	.04
Oil from oil shale	[7] 200.00	([6])	1,200.00	([6])	----------	13.08
Natural gas	[8] 180.38	4.710	180.38	4.71	38	1.96

[1] Reserves and production figures converted to B. t. u. according to the following heat values: Anthracite 12,700 B. t. u. per pound; bituminous coal, 13,000 B. t. u. per pound; subbituminous coal, 9,500 B. t. u. per pound; lignite, 6,700 B. t. u. per pound; petroleum, bitumen from bituminous sandstone, and oil from oil shale, 6,000,000 B. t. u. per barrel; and natural gas, 1,000 B. t. u. per cubic foot.

[2] 30 percent of reserves as shown in table 1, determined by a consideration of 5 States for which reserve estimates have been classified by thickness of bed and overburden. The estimate is intended to show reserves of measured and indicated coal in beds at least 28 inches thick under no more than 2,000 feet of overburden.

[3] Includes 3.73 billion barrels of natural gas liquids.

[4] Estimate by the American Petroleum Institute.

[5] 50 percent of measured and indicated reserves of bitumen from bituminous sandstone in deposits near Vernal and Sunnyside, Utah; Casmalia, Santa Cruz, and Edna, Calif.; and Uvalde, Tex.

[6] Negligible.

[7] 60 percent of measured reserves of oil shale containing 15 barrels of oil per ton, as estimated by Carl Belser in Oil Shale Resources of Colorado, Utah, and Wyoming, American Institute of Mining and Metallurgical Engineers Technical Publication 2358, 1948.

[8] Estimate by the American Gas Association.

For coal, the figures in table 3 are derived from the most recently available data of the United States Geological Survey and other sources, but include only the estimated quantity of coal in measured and indicated categories in beds 28 inches or more thick and under no more than 2,000 feet of overburden. The figures for oil from oil

shale and bitumen from bituminous sandstone are believed to be conservative. On this basis of classification as "assured recoverable" the fuel reserves of the United States have been compared in terms of the British thermal units they represent. Coal of all ranks represents about 83 percent of the total, oil from oil shale about 13 percent, and petroleum and natural gas slightly less than 2 percent each, the whole representing more than 9,000 quadrillions of B. t. u. in assured recoverable reserves as compared with an average annual production over the past decade of slightly more than 30 quadrillion B. t. u. annually.

These quantities classed as assured recoverable reserves do not, of course, represent all the energy from mineral fuels that may ultimately be available for use. A tentative appraisal of these ultimately recoverable reserves is shown in table 4 and total more than three times those shown as assured.

Because of the nature of the occurrence of oil and gas in the ground, the basic reserves of these fuels cannot be calculated and can be estimated only by inference. They are mobile substances that move through minute openings in the rocks and accumulate only where geologic conditions provide traps that prevent further migration. Because of the great variety of structural and stratigraphic relations that create such traps, the total number of traps cannot be predicted, and the total volume of oil and gas contained in them cannot be ascertained in advance of drilling and development.

Attempts, however, have been made to estimate the total amount of recoverable oil and gas that may ultimately be obtained.

The figures shown for petroleum and natural gas are based on attempts to estimate the ultimately recoverable quantities on the assumption that the total volume of marine sedimentary rock in the United States within range of exploration by drilling will yield petroleum and natural gas in amounts proportional to the yields obtained from the volume of rock that has been drilled thus far. There is some approach to agreement among the several published estimates as to the order of magnitude of these ultimately recoverable reserves. It may well be questioned, however, whether this concurrence represents an approach to accuracy, or whether it represents, at least in part, the present state of development of basic data from which even the best informed might draw similar though inaccurate conclusions. The estimates of yields to be obtained from the volume of rocks explored thus far may, for example, be substantially exceeded if new, now unforeseen, discovery techniques should permit the location of deposits of oil and gas directly rather than merely the location of traps in which oil and gas may be found. Before the utilization of seismic methods of exploration, much lower estimates of yield to be obtained from the volume of rocks explored would have been likely. It is entirely possible that we may eventually look back with surprise to the fallibility of the conclusions of those who are now best informed.

The figures for ultimately recoverable petroleum and natural gas shown in table 4 are thus hardly more than qualitative estimates, although made by highly qualified individuals. They are believed to be subject to substantial increases as new discoveries are made in the volume of rocks thus far explored; to other increases caused by improvements in the technology of discovery and recovery yet to be made; and to such increases as may come from fuller exploration of

the Continental Shelves. These increases may be expected to continue as long as new petroleum and natural gas fields are being discovered. When the discovery rate diminishes, as it will ultimately do, petroleum and natural gas will become relatively more expensive sources of energy. The ensuing period of transition to more extensive use of other sources of energy will in all likelihood be so obscured by irregularities in the rate of discovery and by fluctuations in the economic cycle that it may only be determinable in retrospect.

TABLE 4.—*Total ultimately recoverable mineral fuel reserves of the United States, Jan. 1, 1950*

Type of mineral fuel	Ultimately recoverable reserves and average annual production (coal in billions of short tons; petroleum, bitumen from bituminous sandstone, and oil from oil shale in billions of barrels; and natural gas in trillions of cubic feet)		Ultimately recoverable reserves and average annual production (in quadrillions of B. t. u.) [1]		Ratio of ultimately recoverable reserves, as currently appraised, to average annual production, 1940–50	Percent of total ultimately recoverable mineral fuel reserves on B. t. u. basis, Jan. 1, 1950
	Ultimately recoverable reserves, Jan. 1, 1950	Average annual production, 1940–50	Ultimately recoverable reserves, Jan. 1, 1950	Average annual production, 1940–50		
Coal:						
Bituminous coal	616.32	.544	16,024.32	14.14		55.14
Subbituminous coal	233.85	.007	4,443.15	.13		15.29
Lignite	355.73	.003	4,766.78	.04		16.40
Anthracite and semianthracite	6.89	.057	175.01	1.45		.60
Total coal, all ranks	[2] 1,212.79	.611	25,409.26	15.76	1612	87.43
Petroleum	[3] 61.07?	1.780	366.42?	10.68	34?	1.26
Bitumen from bituminous sandstone	[4] 1.25	([5])	7.50	([5])		.03
Oil from oil shale	[6] 500.00	([5])	3,000.00	([5])		10.32
Natural gas	[7] 277.64?	4.710	277.64?	4.71	59?	.96

[1] Reserves and production figures converted to B. t. u. according to the following heat values: Anthracite, 12,700 B. t. u. per pound; bituminous coal, 13,000 B. t. u. per pound; subbituminous coal, 9,500 B. t. u. per pound; lignite, 6,700 B. t. u. per pound; petroleum, bitumen from bituminous sandstone, and oil from oil shale, 6,000,000 B. t. u. per barrel; and natural gas, 1,000 B. t. u. per cubic foot.

[2] Tables 1 and 2.

[3] Recoverable reserves of petroleum remaining after subtracting petroleum production to Jan. 1, 1950, from original petroleum reserves of 100 billion barrels, as estimated by W. E. Pratt in Our Oil Resources, second edition, edited by L. M. Fanning, McGraw-Hill Book Co., New York, 1950. Figure does not include Continental Shelves.

[4] 50 percent of estimated measured, indicated, and inferred reserves of bitumen from bituminous sandstone in deposits near Vernal and Sunnyside, Utah; Casmalia, Santa Cruz, Edna, Sisquac, Sulphur Mountain, and San Ardo, Calif.; and Uvalde, Tex.

[5] Negligible.

[6] 50 percent of reserves of oil in oil shale deposits having an average content of 15 barrels of oil per ton, as estimated by D. C. Duncan, U. S. Geological Survey. Personal communication.

[7] Recoverable reserves of natural gas remaining after subtracting natural gas production to Jan. 1, 1950, from original natural gas reserves of 400 trillion cubic feet, as estimated by L. F. Terry in Our Oil Resources, first edition, edited by L. M. Fanning, McGraw-Hill Book Co., New York, 1945. Figure does not include Continental Shelves.

FACTORS INFLUENCING FUTURE CONCEPTS OF RESERVES

The total amount of energy in mineral fuels is reassuringly large. These deposits of the mineral fuels represent the stored and concentrated solar energy accumulated over many millions of years of geologic time. They are irreplaceable; once recovered and put to use, they are gone. Other sources of energy now supplement to some degree

the energy derived from mineral fuels and doubtless will be the source of an even larger increment in the future. Among these are the power of running water, the wind, and the tides, the energy of the sun's rays either directly or through photosynthesis, and the oldest of all energy sources, the combustion of vegetation. Looming large though very intangible is the energy that may be derived from atomic fission. Some of these possible sources of energy are not now assured substitute sources for the energy presently derived from mineral fuels. Accordingly, it behooves us to attain the most efficient use of the energy in our reserves of mineral fuels. The primary step in measures necessary for wise use is a continuing effort to obtain a definitive knowledge of the basic reserves of the several mineral fuels.

At present only about 30 percent of the total coal reserves of the United States can be said to be known to the approximately correct amount. The remainder is only inferred to be present from available information on the distribution and thickness of coal-bearing rocks and its true quantity remains to be determined. Large areas of the coal-bearing land of the United States, particularly in the Western States, have never been adequately mapped and the data obtainable on their coal resources summarized. Still larger areas are overlain by relatively thin but effectively concealing mantles of surface deposits of various kinds so that much exploratory drilling will be necessary to learn the thickness and extent of the underlying coal beds. Similar deficiencies exist in our basic data on reserves of oil shale and asphaltic sands. For petroleum and natural gas, as has been shown, our basic reserves are not susceptible of accurate computations. The basic data needed for improvement in these estimates can in part be acquired by more detailed geologic investigations of volume, distribution, organic content, and interrelationships of the sedimentary rocks in which oil and gas are to be sought, but most of the needed data will be furnished only by the continuation and expansion of the exploratory drilling process that has already contributed so impressively to our knowledge of the three-dimensional geology of the United States.

Even were we in full possession of the basic data on our reserves of fuels in the ground, much would remain to be done in promoting maximum efficiency in discovery of new sources, in recovery techniques, in processing, and in utilization; all of these and the comparative situation of the remainder of the world with respect to reserves, cost of production, and transportability of the product have a continuing impact on what our recoverable reserves can be considered to be at any period of time. Only in appraisal of the basic geologic data and in the conception and application of new modes of discovery thinking and new techniques of discovery does the geologist have a large share of responsibility. For the fuels as for many other minerals, the other technologic and economic factors have at least an equally significant part in determining our Nation's future ability to supply itself and its citizens with the heat, light, and power requirements needful for our defense and continued progress to higher levels of civilization.

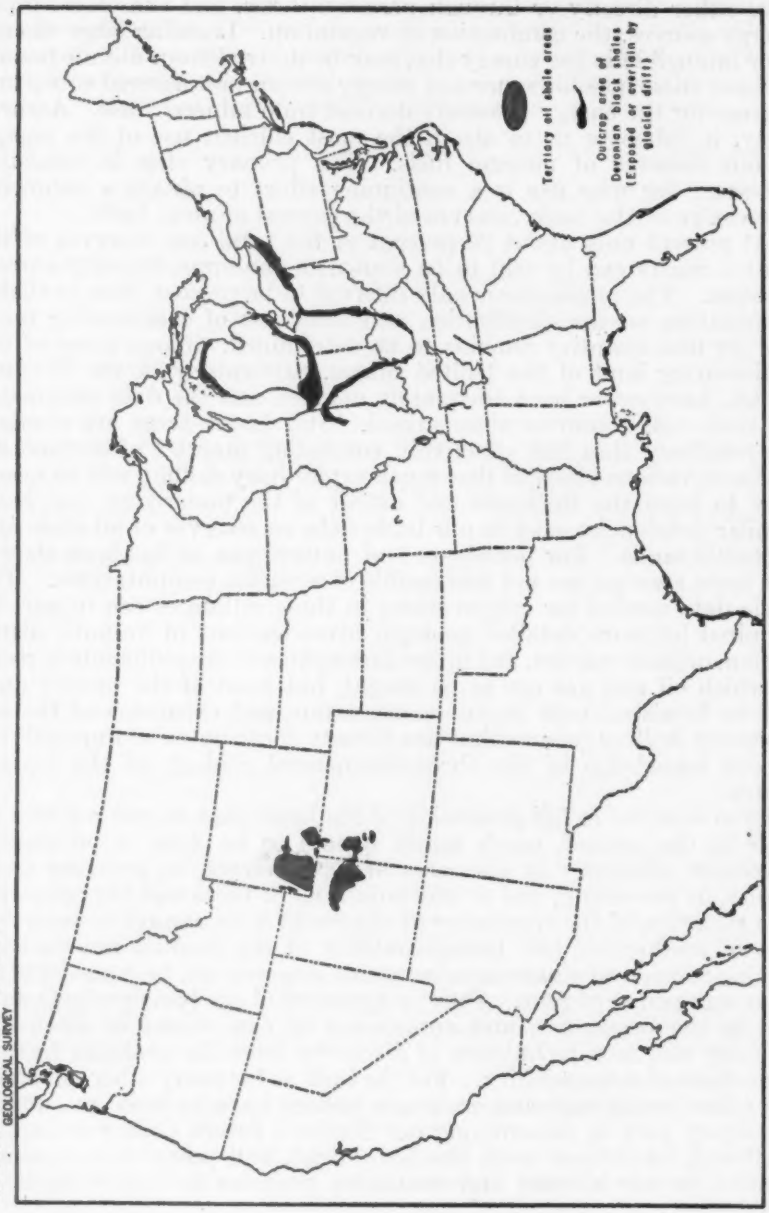

Tertiary oil shale areas
Outcrop area of Devonian black shales (Exposed or overlain by glacial drift)
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PRINCIPAL OIL SHALE DEPOSITS OF THE UNITED STATES

FIGURE 14

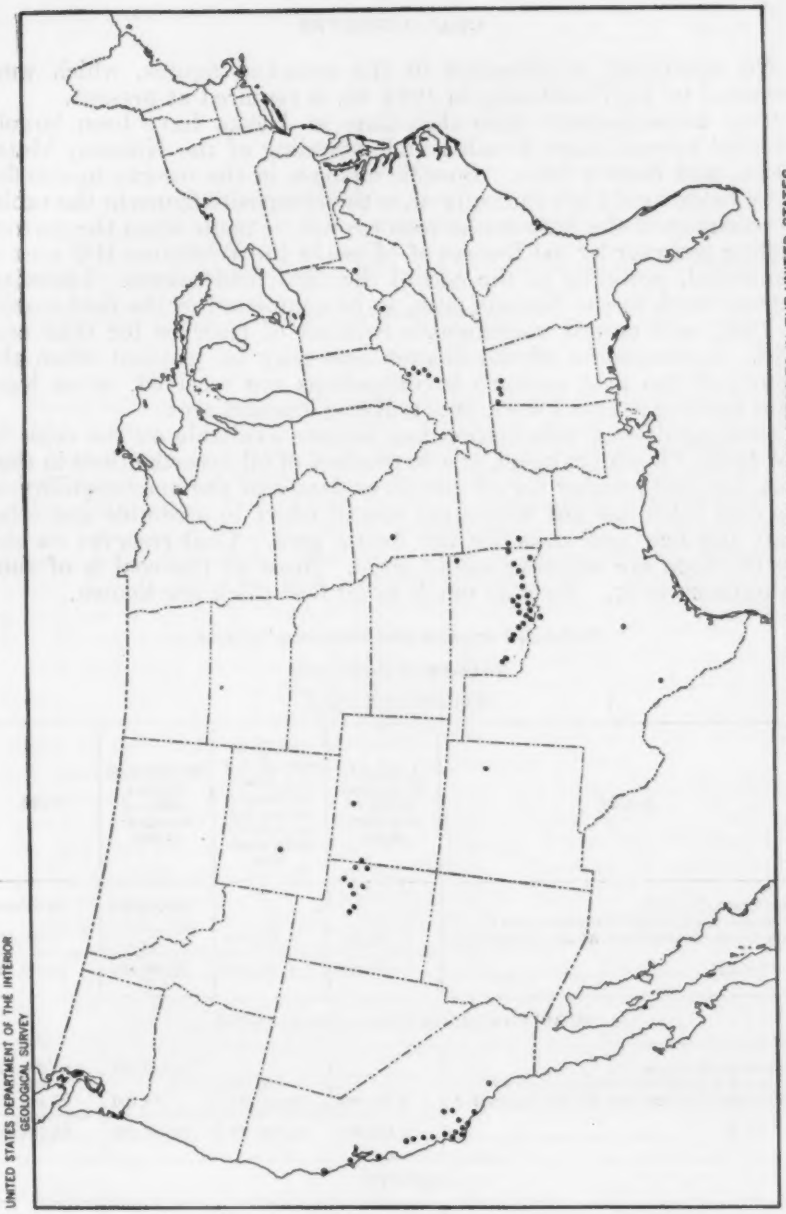


FIGURE 15

MAP SHOWING GENERAL DISTRIBUTION OF ASPHALT AND BITUMINOUS ROCK DEPOSITS IN THE UNITED STATES

Fuel Reserves of Alaska

Statement by Alaskan Section,[46] United States Geological Survey

COAL RESERVES

No significant modification in the attached figures, which were prepared by C. Wahrhaftig in 1944–45, is required at present.

Coal investigations since that time in Alaska have been largely oriented toward more detailed understanding of the Nenana, Matanuska, and Homer fields. Specific changes in the reserve figures for these fields would not radically alter the composite figure in the table. Reestimates of the Matanuska reserves will be made when the current drilling program by the Bureau of Mines in the Wishbone Hill area is completed, probably at the end of the 1951 field season. Likewise, current work in the Nenana area, to be completed in the field season of 1951, will permit considerable revision of reserves for that coal field. A reestimate of the Homer field may be justified when the results of the past season's investigations are received, or at least after another season's work in this Kenai lowland area.

Some additional information has become available on the coals in the Arctic Ocean drainage, as a byproduct of oil investigations in that area, but the priority for oil resources data and the inaccessibility of the coal fields has not warranted special effort to assemble and integrate the new coal data for the Arctic area. Coal reserves on the North Slope are unquestionably large. Most of the coal is of subbituminous rank. Beds as much as 20 feet thick are known.

Estimated original coal reserves of Alaska

[In thousands of short tons]

BITUMINOUS COAL

Region	Accessible by present means of transportation	Within 40 miles of present means of transportation, but not immediately available	Remote from present means of transportation	Total
Arctic Ocean drainage			22,000,000	22,000,000
Yukon and Kuskokwim drainage basins [1]		(2)		
Pacific Ocean drainage and Alaska Peninsula [3]	450,000	1,350,000		1,800,000
Total	450,000	1,350,000	22,000,000	23,800,000

SUBBITUMINOUS COAL AND LIGNITE

Arctic Ocean drainage			60,000,000	60,000,000
Yukon and Kuskokwim drainage basins [1]		400,000		400,000
Pacific Ocean drainage and Alaska Peninsula [3]	2,400,000	19,600,000	186,000	22,186,000
Total	2,400,000	20,000,000	60,186,000	82,586,000

LIGNITE

Southeastern Alaska	8,000			8,000

See footnotes at end of table, p. 47.

[46] Data for this statement were supplied by the following members of the Alaskan Section of the United States Geological Survey: George Gryc, J. K. Hartsock, P. L. Killeen, D. J. Miller, R. L. Miller, and C. Wahrhaftig.

Estimated original coal reserves of Alaska—Continued

[In thousands of short tons]

ANTHRACITE

Region	Accessible by present means of transportation	Within 40 miles of present means of transportation, but not immediately available	Remote from present means of transportation	Total
Pacific Ocean drainage and Alaska Peninsula [3]	----------	1,000,000	----------	1,000,000
Total, all ranks	2,858,000	22,350,000	82,186,000	107,394,000

[1] Excludes areas south of the Tanana River tributary to the Alaska Railroad and the Richardson Highway.
[2] Present, but quantity unknown.
[3] Includes areas excluded in Yukon and Kuskokwim drainage basins.

OIL AND GAS RESERVES

The extent of oil reserves on the northern slope of Alaska is still very poorly known, despite 5 years of intensive exploration. No figure can be given at this time as to the amount of proved reserves. It is clear, however, that shallow wells can be drilled in two different regions which will produce from a few score to a few hundred barrels of oil per day. The size of the productive area in each of these regions is at the present time unknown. The remoteness of Arctic Alaska from places where the oil could be used and the difficulties and expense of transportation of oil to refining and consuming centers are significant factors in any appraisal of potentialities of reserves in this region.

Gas is known to exist in the Point Barrow region, and one gas well is now producing in that area for consumption at Camp Barrow on the Arctic coast. It is probable that other gas wells can be drilled elsewhere on the North Slope which would be commercial if they were more favorably located with respect to consuming centers.

Between 1902 and 1933 petroleum was produced from the Katalla field in an area of Tertiary rocks along the Gulf of Alaska. Total production was about 154,000 barrels. Destruction of the small refinery by fire in 1933 terminated the operation. Presumably some small reserve of petroleum still is available at these capped shallow wells.

Two belts along the south coast of Alaska are regarded as favorable sites for further search for petroleum reserves: A belt of Tertiary rocks in the Katalla-Yakataga district along the Gulf of Alaska, and the belt of Jurassic rocks along the west side of Cook Inlet and its continuation down the Alaska Peninsula. Investigations by the Geological Survey are in progress on a small scale in each of these belts. One well drilled on the Iniskin Peninsula did tap a small reservoir of petroleum and gas at depth, but not in quantity to support a commercial operation.

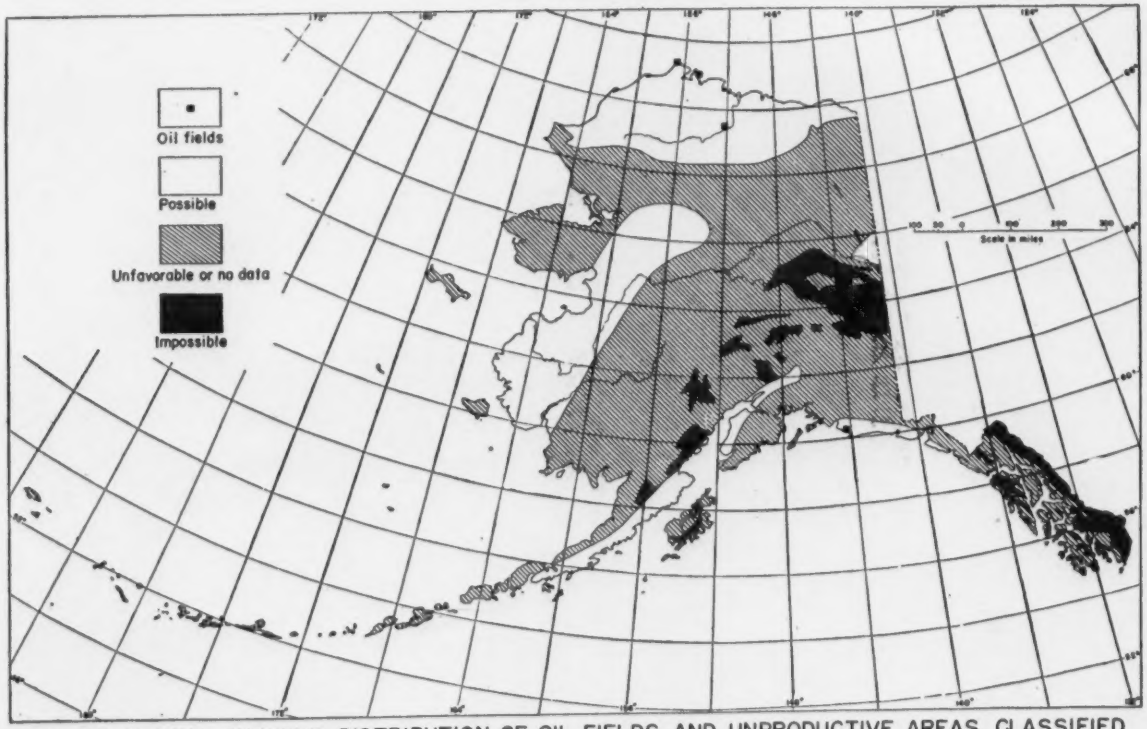
OIL SHALES

Oil shales are known on the Arctic Slope, and at two or three localities elsewhere in Alaska. Samples have been tested from the locality on the Christian River, and from Trout Creek on the Yukon in eastern Alaska. The locality on Besboro Island in the Norton Sound portion of western Alaska has not been verified by the Geological Survey. None of these areas of oil shales have been investigated in an adequate manner as yet.

KNOWN COAL AREAS AND PRINCIPAL COAL MINES OF ALASKA

FIGURE 16

FIGURE 17



MAP OF ALASKA SHOWING DISTRIBUTION OF OIL FIELDS AND UNPRODUCTIVE AREAS CLASSIFIED WITH RESPECT TO THEIR RELATIVE LIKELIHOOD OF YIELDING COMMERCIAL QUANTITIES OF OIL